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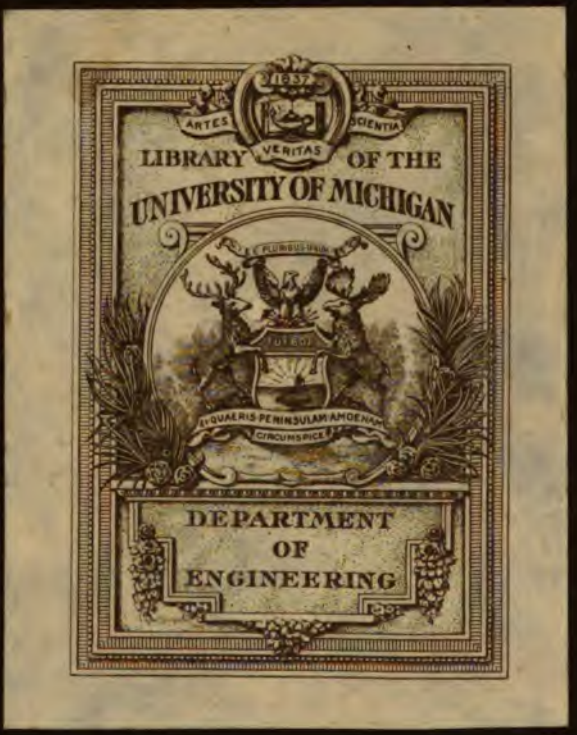
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CLAUDIAN AQUEDUCT (ROME), BUILT IN 50 A.D (*Frontispiece.*)

WATER-SUPPLY

(CONSIDERED PRINCIPALLY FROM A SANITARY STANDPOINT)

BY

WILLIAM P. MASON

PROFESSOR OF CHEMISTRY, RENSSELAER POLYTECHNIC INSTITUTE

Member of the American Philosophical Society, the American Chemical Society, the American Society of Civil Engineers, the American Institute of Chemical Engineers, the American Public Health Association, the Royal Sanitary Institute (Great Britain), the American Water-Works Association, the New England Water-Works Association, the Franklin Institute, Honorary Member Association Générale des Hygiénistes et Techniciens Municipaux (Paris), etc., etc.

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PREFACE

So much material has been added to our stock of general knowledge upon the subject of "Water-supply" since the appearance of the last edition of this book that it has been found necessary to rewrite considerable portions of the original text, and to make many additions thereto.

The writer hopes and believes that acknowledgment has been given whenever material has been extracted from either the published works or private notes of other authors, but he finds himself under obligations to so many persons, both here and in Europe, for courtesies extended and information furnished, that he is quite hopeless of properly recognizing them.

WILLIAM P. MASON.

RENNSELAER POLYTECHNIC INSTITUTE,
TROY, N. Y., November 1, 1916.

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WATER-SUPPLY

CHAPTER I

INTRODUCTORY

FROM remote antiquity the highest value has been set upon an abundant and pure water-supply. Centres of population sprang up in ancient times around those points where it was readily available, and great expenditures of labor and treasure were made to carry it to places where it was not naturally plentiful. Not only was a generous daily *per capita* allowance sought for, but we note in the centuries gone by unmistakable evidences of a keen appreciation of the dangers lurking in a polluted supply, and upon this point many of the ignorant consumers of our own day and generation would be benefited did they consult the wisdom of the past.

Hippocrates, for instance, who wrote upon the value of pure water some four hundred years before the beginning of our era, advised boiling and filtering a polluted water before using it for drinking—advice which all must consider entirely "up to date."

Pliny (A.D. 70) in his "Natural History" (book XXXI, chapters I to VI) devotes large space to the discussion of potable water, and thus speaks of one of the numerous supplies of Rome, which, by the way, is a water in use to-day:

"Among the blessings conferred on the city by the bounty of the gods is the water of the Marcia, the cleanest of all the waters in the world, distinguished for coolness and salubrity."

Libavius in 1595 refers to Pliny's work, and adds the

curious suggestion that the weight of a water is proportionate to its potability.

During the Middle Ages it was observed that water sometimes became poisonous through being distributed in lead pipes.

Although Lascaris, who died in 1493, did not recognize the power of water to intensify and spread certain epidemics, it is interesting to observe that his teachings upon the origin of disease came very near the germ theory of the present day.

The following from *The Hospital* is worth preserving as showing how our ancestors regarded the question of water-drinking:

"It needed a very bold man to resist the medical testimony of three centuries ago against water-drinking. Few writers can be found to say a good word for it. One or two only are concerned to maintain that 'when begun in early life it may be pretty freely drunk with impunity,' and they quote the curious instance given by Sir Thomas Elyot in his 'Castle of Health,' 1541, of the Cornish men, 'many of the poorest sort, which never, or very seldom, drink any other drink, be notwithstanding strong of body, and like and live well until they be of great age.' Thomas Cogan, the medical schoolmaster of Manchester fame, confessed in his 'Haven of Health,' 1589, designed for the use of the students, that he knew some who drink cold water at night or fasting in the morning without hurt; and Dr. James Hart, writing about fifty years later, could even claim among his acquaintances 'some honorable and worshipful ladies who drink little other drink, and yet enjoy more perfect health than most of them that drink of the strongest.' Sir Thomas Elyot himself is very certain, in spite of the Cornish men, that there be in water causes of divers diseases, as of swelling of the spleen and liver. He complains oddly, also, that 'it fitteth and swimmeth,' and concludes that 'to young men, and them that be of hot complexion it does less harm, and sometimes it profiteth, but to them that are feeble, old, and melancholy it is not convenient.' But the most formal indictment against water is that of Venner, who, writing in 1622, ponderously pronounces to dwellers in cold

countries 'it doth very greatly deject their appetites, destroy the natural heat and overthrow the strength of the stomach, and, consequently confounding the concoction, is the cause of crudities, fluctuations, and windiness in the body.'"

Much the larger undertakings connected with ancient water-supply were those built entirely for, or at least in connection with, general systems of irrigation. "The extent of some of these great hydraulic works can be conjectured from the ruins remaining. Lake Moeris, in Egypt, was constructed at least 2000 years before Christ. Its dimensions were sufficient to regulate the annual inundation of the Nile, receiving the surplus waters when there was danger of a flood, and supplying the needed deficiency when the river reached a stage which could not irrigate the crops. This, with other large reservoirs of flood-waters, enabled a population of 20,000,000 to exist in the valley of the Nile, while it now supports barely one-fourth of the number.

"In ancient times the valleys of the Euphrates and Tigris, now almost a desert, were densely populated. Four thousand years ago the rulers of Assyria had converted those sterile plains and valleys into gardens of extreme productiveness by the construction of immense artificial lakes for the conservation of the flood-waters of the river, and great distributing-canals for irrigation. One of these canals, supplied by the Tigris, was over 400 miles long and from 200 to 400 feet broad, with sufficient depth for the navigation of the vessels of that time.*

"In India tanks, reservoirs, and irrigating-canals were constructed many centuries before the Christian era, and a great part of that country was kept in the highest state of cultivation. Some of the tanks or artificial lakes covered many square miles, and were often fifty feet in depth.

"Evidences exist in New Mexico and Arizona that in prehistoric times a race now extinct had extensive irrigation-works and cultivated large areas." (Wyckoff.)

* The Nahrawan Canal. It is of great antiquity, and its former importance is shown by the ruins situated along its course.

Professor F. H. Cushing advises the author of his discovery of ancient reservoirs of large size in southern Arizona.

On the site of ancient Carthage there are still to be seen

THE CISTERNS AT CARTHAGE. ALL THAT IS LEFT OF THE ANCIENT CITY.

the great cisterns for storage of water, eighteen in number, and each about one hundred feet long, twenty feet wide, and nearly twenty feet deep. They were originally covered with

earth, and to-day are in marvellously good repair. They lie in two long rows and empty into a common gallery situated between the rows. They belonged to the ancient or Punic city. *

Drinking-water was supplied to ancient Carthage from a spring in the Zaghoun Mountains some sixty kilometres to the south. The channel way, which the writer found to be only ten inches square in section, contoured the hillsides for considerable distances, at times went under ground, and on approaching the coast was carried on arches of a magnitude seemingly out of proportion to so small a channel. From ten to fifteen kilometres of the old aqueduct yet remain. See illustration, page 6.

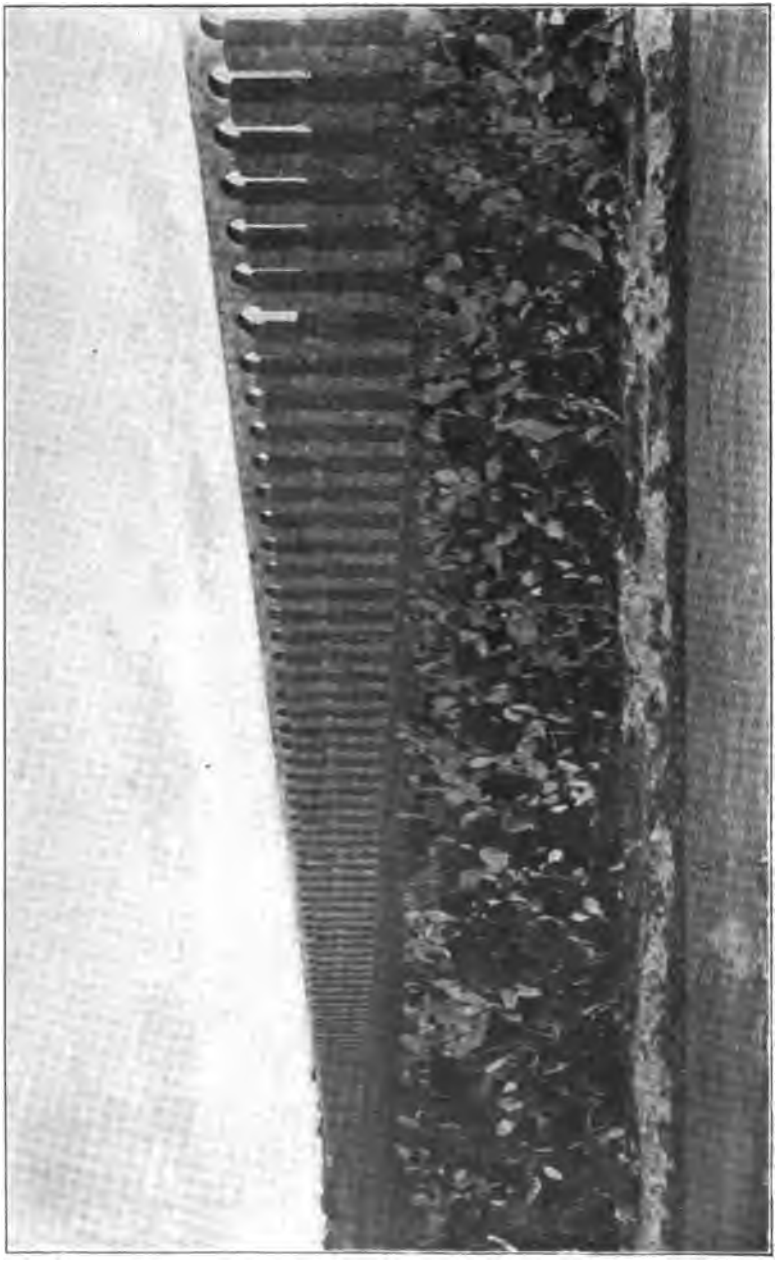
"Amongst the wonderful monuments of the former greatness of the Singhalese people must be mentioned the ruined tanks, with which scarcely anything of a similar kind, whether ancient or modern, can be compared. Thirty colossal reservoirs and about seven hundred smaller tanks still exist, though for the most part in ruins. In February, 1888, the largest and most important tank in Ceylon, that of Kalawewa, was, after four years of labor, completely restored. It was built 460 A.D. to supply Anuradhapura with water, but has been in ruins for centuries. Now again it contains an area of seven square miles of water, twenty feet deep, and supplies smaller tanks more than fifty miles distant." †

When we reflect that these great works of antiquity were accomplished without the aid of steam, electricity, or explosives, we are impressed with the belief that, in intelligent perseverance at least, "there were giants in those days." Our respect does not lessen when we contemplate the extent of the supply of water poured into the "Eternal City."

The following is freely taken from Forbes's lecture on the Roman aqueducts:

* See "Carthage and Carthaginians," by Bosworth Smith.

† Chambers's Encyclopædia, iii. 80.



AQUEDUCT NEAR TUNIS, LEADING TO ANCIENT CARTHAGE.

ROMAN AQUEDUCTS, ARRANGED IN CHRONOLOGICAL ORDER

	Date of Construction.	Length.
Appia	312 B.C.	11 miles
Anio Vetus	272 "	43 "
Marcia	145 "	61 "
Herculea branch	...	3 "
Tepula	126 "	13 "
Julia	34 "	15 "
Virgo	21 "	14 "
Augusta	10 A.D.	6 "
Alsietina	10 "	22 "
Claudia	50 "	46 "
Anio Novus	52 "	58 "
Neronian branch	97 "	2 "
Traiana	109 to 200 A.D.	42 miles
Hadriana	117 to 1585 "	15 "
Aurelia	162 "	16 "
Severiana	200 "	10 "
Antoniniana branch	215 "	3 "
Sabina—Augusta	130 to 300 "	15 "
Alexandrina	226 "	15 "

(The miles above given are Roman, of 4854 feet. The entire length of the aqueducts in English miles would be 381.)

It has been calculated that, altogether, the supply was 332,306,600 gallons daily, which would have been over 332 gallons *per capita* upon a basis of a population of one million. This calculation, however, has been based upon very indifferent data furnished by Prony in 1817. As Mr. Clemens Herschel has lately shown, a much more probable figure for the daily water consumption of the world's capital should read thirty-two million U. S. gallons.

Notwithstanding that some of the Roman aqueducts were damaged during the wars of the sixth and seventh centuries, the supply did not entirely cease until the fourteenth century, when Rome was abandoned by the papal court. In the present day four of the ancient sources still supply the city with water.

Of the imposing lines of arches which stalk across the Campagna none is more interesting than the stately Claudian aqueduct. (See frontispiece.)

Speaking of it, Pliny says: "The preceding aqueducts have all been surpassed by the costly work more recently commenced by the Emperor Caius and completed by Claudius. The sum expended on these works was 350,000,000 of sesterces." *

Near the city the Claudian arches were filled up by Aurelian, and made to do duty as part of the city wall, the great gateway permitting passage at this point being known as the Porta Maggiore.

It is curious to observe that waters from different sources were carried in separate channelways upon the same arches.

Speaking of the Marcia, Tepula, and Julia waters, Frontinus says: "The three are carried on the same arcade, the highest being the Julia, then the Tepula, and lowest the Marcia." Near the Porta Maggiore the three channels are still distinctly to be seen.

It remains to say a word about the "castella" so often found along the courses of the Roman aqueducts. Forbes calls them "filtering-places," but such they could not have been—at least in the modern acceptation of the expression. They varied in size and in the number of their chambers, some having but four, while others numbered as many as twelve compartments. One of the smallest size is illustrated on p. 9.

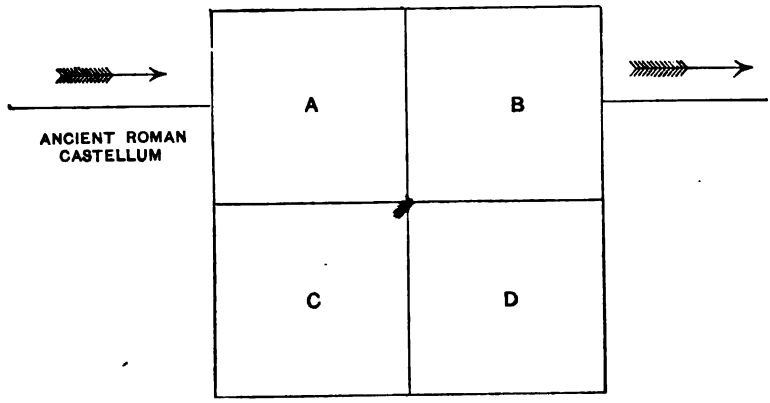
The water entered chamber *A* and passed by means of holes in the floor into *C*, thence through openings in the wall into *D*, from which it rose through holes in the floor into *B*, and then passed on to Rome. A breaking of undue "head" would take place in the "castellum," as is accomplished in a more modern fashion at Vienna to-day; † but the real benefit

* About $12,700,000.

† At Vienna the aqueduct has a fall of 11,000 feet in the first 10 miles, and 10 feet per mile the remainder of the way. It is about 60 miles long. The "head" is throttled by gates, every 100 feet of fall on the upper section. See Engineering News, Nov. 29, 1894.

derived from the construction of these chambers was probably the opportunity given for sedimentation.

Thus Frontinus says: "At the seventh mile, on the Via Latina, the Marcia, Tepula, and Julia are taken into a covered



'filtering-place,' where, as though breathing again after their course, they deposit mud."

So far as quality of water is concerned, it is probably true that the ancient public supplies were better than the average of what is furnished to our cities to-day, for the reason that pumping was unknown and the water-purveyors were of necessity driven to distant and purer sources to the exclusion of local rivers which lay too low to be utilized.

CHAPTER II

DRINKING-WATER AND DISEASE

In that excellent treatise upon "Water-supplies and Inland Waters" issued by the Massachusetts State Board of Health, waters are classified as "normal" and "polluted," the former being such as are free from addition, directly or indirectly, of either sewage or industrial waste.

The relation of "normal" waters, as a class, to sanitary science constitutes a subject by itself, and one shrouded in much confessed ignorance and conflicting testimony, as is instanced by the doubt we entertain of the effect of "peaty water" upon the human organism.

Bog-waters in Ireland, especially those of Lough Sheighs in the county of Cavan, and of Lough Neagh, have long been used for the treatment of skin-diseases. The mineral waters of Askern, in Yorkshire, England, are about saturated with peaty material from the neighboring bogs, and have for many years been successfully used in the treatment of chronic rheumatism and skin-diseases.

Bothamley thinks it not improbable that the dissolved peaty matter is the curative agent in these waters.*

"Certain affluents of the Orinoco and Amazon have what are called black waters (*aquas negras*). When seen in mass, they are of a coffee-brown or of a greenish black. In the shade they are almost black, but in a glass they are brownish yellow, though very transparent. They have no disagreeable taste, and are preferred for drinking.

"The waters do not undergo any chemical change on keeping." †

* J. Chem. Soc., lxiii. 696.

† Chem. News, lviii. 305.

This ability to "keep well" is very frequently observed in brown waters, but it is by no means universal, nor does it seem to be a necessary characteristic indicating potability.

In writing to the author regarding the water of the Dismal Swamp of Virginia, Surgeon-General J. R. Tryon, of the U. S. Navy, said:

"I beg to enclose herewith copy of analysis made of Lake Drummond (Dismal Swamp) water in October, 1891, at the Naval Museum of Hygiene.

"This has always been considered a very pure water, and before the general adoption of condensers was much used for naval vessels. The bureau has no special data bearing upon the relation to disease with the use of the class of waters referred to," i.e., "peaty" waters.

ANALYSIS OF LAKE DRUMMOND WATER

(Parts per Million.)

Color	Yellow
Odor	Sweetish
Turbidity	None
Sediment	Very slight
Residue on evaporation	294.0
Loss on ignition	258.0
Fixed solids	36.0
Free ammonia	.016
Albuminoid ammonia	1.75
Nitrogen as nitrites	None
Nitrogen as nitrates	5.00
Chlorine	1.50
Hardness	49.3

(For data in general regarding the analysis of water, interpretation of the same, method of taking samples, methods of analysis, etc., reference may be made to the author's book on *Examination of Water*.)

Many of the surface-waters of Massachusetts are colored brown, especially that of the Acushnet River, supplying the

town of New Bedford. Experiments made with this water showed that its dissolved nitrogenous matter remained permanent for months without the development of "free ammonia," or other indications of decay.*

As illustrating the undesirable character of some swamp-waters, the celebrated case of the ship Argo may be called to mind; an incident too often recited to bear repetition here.†

It has been the author's fortune to meet with but few cases of illness traceable to peaty waters, and in all such instances the patients suffered from a mild and transient form of diarrhœa, caused by water from a low-lying, shallow lake or pond, surrounded by low wooded banks. Whatever be the morbific principle of such waters, it appears to be removed by suitable filtration.

Mrs. E. H. Richards very properly points out that such peaty waters as are found unwholesome may owe their toxic qualities to the presence of materials other than the brown coloring matter.

When we dwell upon the fact that the milder enteric disorders rarely get into the "death-rate," and that visiting strangers may suffer from a cause to which the acclimated natives are not susceptible, we appreciate that in dealing with peaty water we must consider it as largely an unknown quantity, probably entirely harmless, but yet the possible centre of trouble, especially if the amount of organic matter present be large. Even the same water may not at all times be equally potable, for, as J. W. Mallet has well said: "It seems quite conceivable that a water containing organic matter of any kind may be harmless at one time and harmful at another, when perhaps a different stage of fermentation or putrefactive change may have been entered upon, and special organisms may have made their appearance or entered upon a new phase of existence. Thus there might possibly be safety in drinking a peaty water, or water filtered through beds of dead forest leaves, when fresh; danger when, after a certain amount of

* Mass. Bd. Health, 1890, 547.

† Parke's "Hygiene."

atmospheric exposure, bacterial organisms had become developed; and safety, again, perhaps, after the growth of such organisms had fallen off and more or less of the available organic matter had been consumed."

When, therefore, the question arises as to the advisability of introducing a peaty water as a town supply, the possibly unsatisfactory character of the same must always be borne in mind, and the municipal authorities should be prepared for the probable necessity of constructing a filtering-plant. Moreover, the likelihood of a filter-plant being required will increase as the years go by, for the people are fast inclining towards a demand for a clear and bright water as well as one that is potable. Furthermore, a distinction should be always drawn between a flowing water carrying fresh peaty material in solution and a water derived from a stagnant swamp. "In certain cases it may be a fact that the algæ decay rapidly but that new growth absorbs the products of decomposition, so that they do not accumulate in the water. Shallow, stagnant bodies of water, which in the heat of summer are full of vegetable and animal life, become in time foul, because decay gets ahead of growth and the products of decomposition accumulate."

"*Malaria and Drinking-water*" was the title of papers formerly found in our sanitary press.

Surface waters and those from shallow wells in "malarious" districts were accused of producing the fever by an accumulation of testimony that was at the time difficult to resist; but the matter has been thoroughly investigated and we now know that "malaria" is due to the bites of infected mosquitoes and that water is not a cause.

Odors which at times occur in water, and which are variously described as "musty," "fishy," "cucumber," "green-corn," "horse-pond," and the like, are produced by the growth, death, and decay of minute organisms, especially those known as algæ. However objectionable these odors

and tastes may be from an æsthetic standpoint, it has not been proven that they are directly productive of disease.

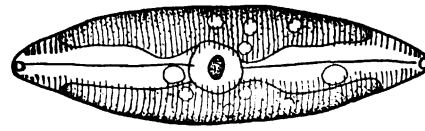
D. D. Jackson has shown * that the odors caused by living microscopical organisms are due to compounds of the nature of essential oils; and Whipple points out that the amount of such oil produced by an abundant growth of the organisms is quite sufficient to account for the effect observed.†

He notes, for comparison, that oil of peppermint can be recognized when diluted with water in the proportion of one part of oil to fifty million parts of water; and that when *Asterionella* is present to the extent of fifty thousand organisms per cubic centimetre the dilution of its oil is in the proportion of about one part to two million parts of water.

Whipple further suggests that the flow of water through pipes may cause disintegration of organisms with liberation of the odor-producing oil; hence the odor at the tap may be greater than at the intake. May it not be, however, that the "tap" odor is of mixed quality, partly due to products of decomposition?

This matter of odor and taste is again considered under "stored water," page 318.

The droplets of oil above referred to are shown in the following "camera lucida" drawing of a diatom. The drawing was made by Mr. W. H. Long.‡



Although natural waters are to be found bearing in solution large quantities and varied assortments of mineral ingredients, yet such cannot be considered potable, except in the sense that that are medicinal, and they consequently do not find place in

* Tech. Quarterly, x. 419.
† Microscopy of Drinking-water, p. 195.
‡ Bul. Univ. Texas, v. 22.

the present writing. When those minerals are present, however, which give to the water the characteristic known as *hardness*, the case is quite different, for such a property obtains, to a greater or less degree, in every public supply. As to the wholesomeness of such a water, there is a widespread opinion that a high degree of hardness is not compatible with safety; but although hard waters do often produce certain intestinal derangements, notably constipation, in persons not accustomed to their use, there are no sufficient statistics on record tending to confirm the popular belief that their ingestion leads to the formation of urinary calculi. It is a matter of common observation that sudden change from the use of a pure, soft water to one equally pure, but harder, or *vice versa*, results in temporary intestinal derangement, showing the difficulty to be due rather to the change than to the inherent character of the water employed. While considering the wholesomeness of hard water the English Rivers Pollution Commission (Sixth Report) collected the following statistics, the comparison having been made between towns of the same class, in which the general conditions of life are similar. The conclusion was: "Where the chief sanitary conditions prevail with tolerable uniformity, the rate of mortality is practically uninfluenced by the softness or hardness of the water."

TOWNS SUPPLIED WITH SOFT WATER

Kind of Town.	Number of Towns.	Average Population.	Average Annual Mortality per 1000 Inhabitants.
Seaport	5	162,801	29.4
Inland manufacturing	5	172,860	29.7
Inland non-manufacturing	8	10,751	25.4
Watering-places	5	48,430	19.5

TOWNS SUPPLIED WITH MODERATELY HARD WATER

Seaport	3	226,172	32.1
Inland manufacturing	8	108,715	26.9
Inland non-manufacturing	4	62,372	26.0
Watering-places	3	33,480	19.2

TOWNS SUPPLIED WITH HARD WATER

Seaport	6	116,406	25.1
Inland manufacturing	5	144,981	25.5
Inland non-manufacturing	20	29,169	23.2
Watering-places	12	53,170	20.4

More recently Dr. J. C. Thresh, Medical Officer of Health for the county of Essex, England,* gave statistics showing that, in the areas supplied with hard water, the death-rate is as low, or lower, than in those furnished with soft-water. He concludes that " the character of the water supplies in the county had no effect upon the death-rates." His figures, which follow, indicate the average annual deaths per 1000 population for the years 1907–1911 inclusive; and for 1912 separately.

	Death-rate 1907–11.			Death-rate 1912.		
	Average.	Extremes.		Average.	Extremes.	
		Max.	Min.		Max.	Min.
Soft water area	11.0	11.2	8.9	10.0	11.5	8.7
Moderately hard water areas:						
Country towns	11.5	12.8	7.9	10.9	14.0	7.6
South Essex	11.2	13.0	8.8	9.9	10.6	6.2
Hard water area:						
Country towns	11.2	14.1	8.0	9.9	12.9	7.1
Metropolitan	11.1	12.1	8.5	10.6	11.1	7.2

The " hardness " referred to he describes as:

" Soft," under 10 degrees, i.e., 143 parts per million.

" Moderately hard," from 10 to 20 degrees, i.e., 143 to 286 parts per million.

" Hard," from 20 to 30 degrees, i.e., 286 to 429 parts per million.

These are English notions of " hardness." In the United States we classify waters as:

" Soft," 50 or less parts per million of " hardness."

" Hard," 100 or more parts per million of " hardness."

" Doubtful," between the above figures.

* Water and Water Engineering, April 15, 1914.

Dr. Allfrey practiced medicine a great many years in Kent (England) and was familiar with the very hard water of the district. He states: "The hardness was an intolerable nuisance," but he "had not observed that it was in any way injurious to health, or predisposed in any way to gouty ailments as was popularly supposed." *

The following Massachusetts data collected by A. L. Gammage † entirely support those already given and indicate no relation between hardness and health.

RELATION BETWEEN WATER HARDNESS, TYPHOID AND TOTAL DEATH RATES IN MASSACHUSETTS

Ground Waters—34 Cities and Towns.	Average Hardness, Parts per 1,000,000.	Death Rates per 1000.	
		Typhoid.	Total.
Softest	17	0.08	14.18
Medium	29	0.14	15.71
Hardest	71	0.11	14.12
Surface Waters—39 Cities and Towns.			
Softest	5.7	0.115	14.99
Medium	17	0.10	13.85
Hardest	41	0.14	14.98

Production of goitre through the drinking of certain waters, particularly those derived from the melting of ice or snow, has been widely commented upon. For instance:

"In Bozel there was a population of 1472 people. Of this population no fewer than 900 had goitre and 109 were cretins. The water supply was hard and contained sulphates of calcium and magnesium. The authorities laid on a soft water and sixteen years later the number of persons suffering from goitre was reduced to 39 and the number of cretins to 58." ‡

According to Dr. Rupert Farrant, surgical registrar to the Westminster Hospital, "Goitre is common in the valleys of mountainous districts. The water supply in these districts

* J. Royal San. Inst. 26: 682.

† Engineering News, December 2, 1915.

‡ J. Royal San. Inst., 34: 299.

is of surface origin, and so liable to surface pollution, as it neither passes through filtering beds nor stands in volume. Water derived from snow is open to surface contamination, and, as shown by Houston, micro-organisms survive longer in water at lower than at higher temperatures. The *coli*, being placed under abnormal conditions, either in the water or in the upper part of the intestinal tract, undergo mutation. The mutants are present in the fæces of individuals affected with endemic goitre, and when once lodged there may remain for many years. Dr. Farrant concludes that endemic goitre is preventable by the avoidance of water contamination and by the sterilisation of contaminated water."*

Apparently the filtration of water has no effect on the goitre-producing substance in it. This has been demonstrated by Bircher, who "gave to monkeys, imported from Africa to Hamburg, the water of a certain locality where goitre is endemic. They all showed enlarged thyroids. He tried the same water, after filtration, with like results. Monkeys which were given this water boiled showed no thyroidal enlargements." †

In an article on "The Importance of Magnesia in Drinking-water" ‡ Percy Frankland shows that a very great percentage of the population of England are to-day using waters containing from 40 to 60 parts of MgO per million; and that consequently the prejudice existing against magnesian waters, on account of their supposed production of calculi, goitre, and cretinism, should not be given undue importance.

In 1889 Professor Kocher investigated the occurrence and distribution of goitre in the canton of Bern, Switzerland, and published an interesting map showing the varying frequency of the disease with change of geological conditions.§ He was, moreover, able in a few instances to definitely classify certain local waters as producers or non-producers of goitre. The

* Water and Water Engineering, May 15th, 1915.

† Albany Med. Anal., Dec., 1914.

‡ International Congress of Hygiene, London, 1891.

§ Vorkommen und Vertheilung des Kropfes im Kanton Bern.

analyses of two such waters are here given, in parts per million:

	Producing Goitre.	Not producing Goitre.
Specific gravity at 17° C.	1.000316	1.00041
Lime (CaO)	79.	80.7
Magnesia (MgO)	5.4	10.9
Calcium sulphate ($CaSO_4$)	9.01	36.1
Chlorine (Cl)	4.97	7.
Silica (SiO_2)	3.3	4.5
Iron and alumina	traces	traces
Organic matter	"	"
Nitrates	"	"
Nitrites	none	none
Ammonia	"	"
Iodine and bromine	"	"

It is interesting to note in the above analyses that the magnesia, about which fears have been expressed, is much larger in the non-goitre-producing water than in that which is credited with causing the disease.

Professor Kocher has made cultures of the bacteria occurring in the two classes of water, and has injected rabbits therefrom, with the result that glandular swellings have been produced in several of the animals treated with preparations from the "goitre-water." Nothing definite has, however, been as yet secured, and our present knowledge upon the subject is in a very unsatisfactory state.

Philippe,* after commenting upon the various theories advanced to account for the occurrence of goitre, concludes that "practically nothing is known as to the true cause of the disease."

An article, with map, prepared by Dr. Thierry on "Goitre, and the question of supplying Paris with water from Lake Leman," will be found in "L'Ean" for September 15, 1913.

Lying between ordinary hard waters and those of a true mineral character is a group, principally of artesian origin,

* Mitt. Lebensm. Hy., 5, 1.

containing sundry objectionable mineral ingredients, such as magnesium chloride, hydrogen sulphide, and the like, and which would hardly be considered potable did they occur in well-watered regions, nevertheless they are thankfully received by people very willing to take almost any water they can obtain.

Turbidity is exceedingly common in the river-waters of this country, particularly in those of the great central basin. The quantity of suspended claylike material present naturally varies in each stream with the conditions of the season, being at times entirely absent in some of them, while with others the existence of more or less muddiness appears to be a constant characteristic.

Ockerson reports that four different surface-samples of Mississippi river-water contained 576, 788, 1030, and 348 parts per million of sediment. On July 2, 1894, the same river-water, at New Orleans, contained 2360 parts per million of solids, mostly silt. Below the junction of the clear Mississippi with the muddy Missouri, the two waters flow on for miles, side by side, with a distinct line of separation.

With reference to the influence of the suspended mineral matter upon health, we find some conflict of opinion. It is an unquestioned fact that very roily water is ingested by many of our communities with no traceable evil results, but the preponderance of testimony goes to show that immunity is attained by continued use, and that the visiting stranger is not upon the same platform of safety with the acclimated native.

In reply to the claim so often advanced that turbidity is a positive advantage, as tending to remove objectionable material from a sewage-polluted river-water, it should be stated that suitable arrangements for sedimentation must be furnished, otherwise no advantage can be expected from the mere presence of the suspended mineral ingredients. It is a well-known fact that precipitating solids will drag down with them other finely divided substances which, if left to themselves, would require long periods of time for complete sedi-

mentation, and that even soluble salts may be in part carried down by the same cause.

It may readily be conceived that, acting in obedience to this principle, the depositing silt would gather to itself, and carry with it, many germs of disease which, if left to themselves in clear water, would require much longer time to fall; but that there is any advantage to be looked for in using a turbid water without sedimentation, and thereby swallowing turbidity, germs, and all, is scarcely rational.

The following is in illustration of the influence of turbidity in causing a more rapid deposition of bacteria diffused throughout a body of water. The results represent the relative numbers, per cubic centimetre, at the surface of a body of water, and at varying depths in the same, under the condition of clearness and also under that of material turbidity.

The experiment was conducted with a tall tin vessel, one foot in diameter, and tubulated at intervals of one foot, to allow drawing of samples. The time of settlement was made two hours; and the numbers of bacteria found per cubic centimetre at the successive depths are stated in terms of the number in the surface sample, that being called one hundred.

	Muddy Water	Clearer Water.
Surface	100	100
Depth of one foot	134	125
Depth of two feet	166	142
Depth of three feet	186	169
Depth of four feet	266	254

Two hours of settlement were not enough to bring out marked contrast between the waters, although the principle was sustained.

The really serious item of contamination, the one to which the sanitarian's attention is most quickly drawn, is that of *sewage pollution*, and a consideration of the questions arising upon this topic dwarfs all others into comparative insignificance.

"To those of us who never had our attention called to the fact, it may be something of a revelation to know the amount of waste necessarily disposed of in our great cities. For instance in London this waste has been estimated closely for 1000 people at 260 tons per annum, or over 2½ tons per person per annum. This estimate, of course, includes all characters of waste, like ashes, papers, cans, etc., as well as sludge, but omits the vast amount of water separated from the sewage in forming the sludge. Pettenkoffer estimates 90 grams of feces and 1170 grams of urine as the average excrement per diem for men, women and children. This, coupled with a minimum allowance of 159 liters of water for household use, would make a total of 160 liters, or something over 35 gallons of sewage, approximating 280 pounds each day per person." *

The city of New York pours something like six hundred million gallons of sewage into the Hudson River and New York Bay every twenty-four hours, and, upon the completion of the Passaic Valley trunk sewer, about fifty per cent more will be added from cities and towns in New Jersey. This does not include garbage, which is disposed of by other means.

Shall a water once polluted with sewage material be again used for human consumption? If there be danger in such use, what is its nature, what is its extent, and are there available means of averting it? These are popular questions of the day with which the sanitarian has to grapple.

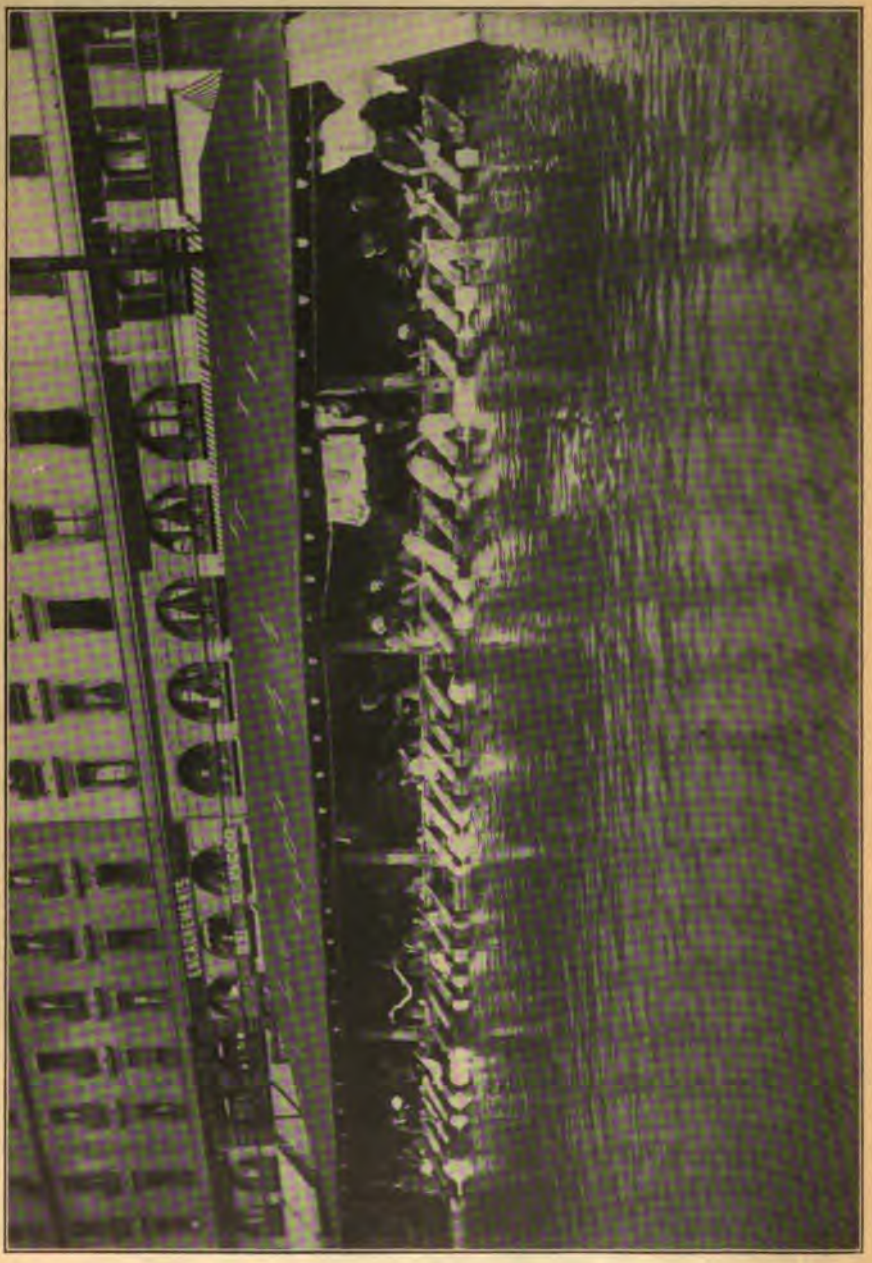
It would hardly be wise to take the reader's time with a *résumé* of matters, possessing only historic interest, pertaining to water pollution; suffice it to say that, within the very recent past, strong views were entertained concerning the self-purification of streams, and also upon certain features of natural and artificial filtration, which we now believe to have been erroneous. That polluted water-supplies have caused widespread illness and death is established beyond a peradventure, and, from among the many illustrations that might be cited,

* N. Y. State J. of Medicine, July, 1910.

the author offers the following in evidence, some of the data having been collected by himself or within his personal experience:

In the autumn of 1887 the city of Messina, Sicily, was visited by an epidemic of cholera. The plague lasted from September 10th to October 25th, during which time there were some 5000 cases and 2200 deaths. Although for a time the number of daily cases was excessive, running as high as 400, the ordinary number was about 70. The population was stampeded, falling from 71,000 to about 25,000. The government felt that a very possible cause for the rapid spread of the scourge lay in a contaminated drinking-water, and an inquiry, resulting in a development of the following facts, fully confirmed the suspicion: The water as it left the gathering-grounds in the mountains was of excellent quality, but it was conveyed to the city in a conduit entirely open. Those who are familiar with European customs will remember that the washing of soiled clothing is there largely an out-of-door occupation, conducted in the nearest available watercourse. For the benefit of the Messina washerwomen a portion of the public water was deflected, before reaching the town, and turned into neighboring washing-pools of stone. A fair proportion of this deflected water, after having been used for laundry purposes, found its way back into the channel, and continued its course to the city. Further contamination occurred within the town itself, for the reason that the mains of the distributing system were of unglazed tile, badly joined, and were laid in the immediate vicinity of unglazed tile sewers, also very leaky. The sewers were at times found on top of, and parallel with, the water-mains.

Acting upon its conviction as to the cause of the great mortality, the government sent tank-ships to the mainland, filled them with pure "Serino" water, supplied the people therewith, and the daily number of cholera cases immediately fell from seventy to five; or, to quote an expression of the time, "the plague ceased as if by magic." A more efficient distributing system has since been introduced, the open con-



POLLUTION OF A STREAM BY THE WASHING OF SOILED LINEN THEREIN—GENEVA, SWITZERLAND.

duit has been replaced by modern pipe, and the city has escaped further visitation by cholera.

From what the author saw, however, it would seem that there is much yet to be done towards bettering the Messina water-supply. Great tanks still exist in the suburban gardens where laundry waste-water is stored for irrigation purposes.

Water from wells in these gardens is taken by the city authorities during periods of scant supply from the regular source, thus permitting certain pollution of the municipal supply.

The influence of the washerwomen in spreading cholera in Messina reminds us that the great epidemic at Cuneo, Italy, in 1884, resulting in 3344 cases, was traced to identically the same source. Infected linen had been washed in a brook communicating with the public water-supply.

In 1890 two violent outbreaks of typhoid fever occurred in the valley of the Tees River.*

The Tees in a small stream of northern England, about seventy miles long, and navigable for about four miles from its mouth.

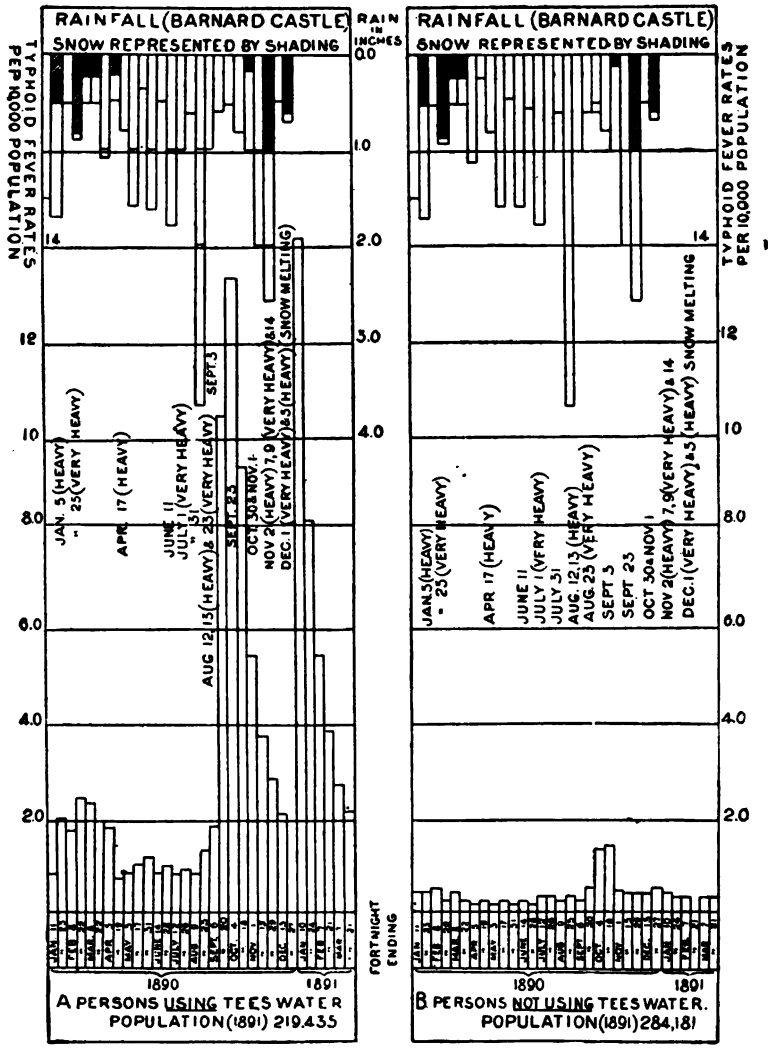
Most of the towns of the valley take their water-supplies from the river, but a large scattered population receives water from other sources. The estimated population using Tees water at the time of the outbreak was 219,435, and the number not using such water was 284,181.

In many places, especially in the towns, the river receives all sorts of polluting additions, which are carried on by the current to the intakes below. During dry weather the stream recedes considerably, leaving uncovered its rocky foreshores, which accumulate filth of every variety, and retain the same until, by reason of heavy rain, the river suddenly rises and sweeps the refuse onward toward the towns nearer the sea.

The result produced upon the thoughtless public of such an extra and concentrated dose of sewage material added to their water-supply is best shown graphically by the accom-

* See 21st Report of the London Local Government Board.

panying chart, where it will be observed that increase of rainfall is followed by increase in cases of typhoid fever among the



RAINFALL AND TYPHOID FEVER IN THE TEES VALLEY, ENGLAND.

219,435 persons using the Tees water, after an interval corresponding to the incubation period of the disease, while no

appreciable result is noticed among 284,181 people of the same district, using other sources of supply.

The "typhoid rates" given in the chart are "cases," not "deaths."

It fell to the author's duty to investigate certain points relating to the typhoid epidemic occurring in the valley of the upper Hudson during the autumn and winter of 1890–91, and the facts secured seem especially instructive.

By a glance at the accompanying chart, the locations will be observed of the several cities and towns situated at and near the junction of the Mohawk and Hudson rivers. Every one of these centres of population drains into the river on whose bank it is situated, and each of them, except Lansingburgh, took at that time all or the greater portion of its water-supply directly from such river by means of pumps. Mark this difference, however, Waterford and Troy were supplied with Hudson River water above the junction of the Mohawk; Lansingburgh was furnished with water from the hills east of the town, and the village of Green Island obtained its water from wells and a filter-gallery driven into sandy soil. The others used Mohawk or Mohawk-Hudson water.*

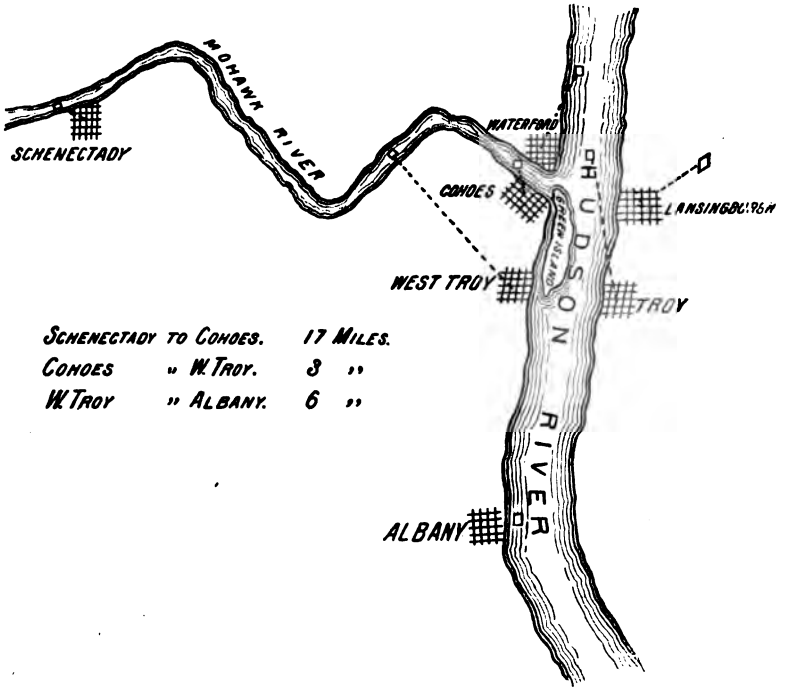
The several intakes are indicated on the chart by squares. Under date of April 11, 1891, the Health Officer of Schenectady wrote the author: "The marked increase in typhoid fever began in July, 1890, and has just let up. We have had about 300 cases. Doctors have not been particular in reporting them, and we have had so many cases of anomalous fevers that diagnosis is questionable. Seventy deaths have been reported." It was not the rule during this epidemic for physicians to do their whole duty in reporting cases. In one instance only two or three cases were reported out of twenty-five. Schenectady is a very old town (at that time of 20,000 inhabi-

* Albany, Cohoes and Waterford have introduced modern filtration plants, Troy has abandoned the Hudson River as a source of supply, and West Troy (now Watervliet) is building works designed to furnish filtered water from the hills.

tants), and its sewerage system delivered the sewage without treatment to the Mohawk river.

The following information was obtained from Dr. Leo, Health Officer of Cohoes, and from Dr. Peltier, his predecessor. Population of Cohoes was 22,000.

" The epidemic of typhoid began in Cohoes about the end of October, 1890, and ceased about the middle of the following



March. Altogether there were about 1000 cases. The cases were mild in character, resulting in very few deaths. Cohoes takes its entire water-supply from the Mohawk and returns its sewage into the same river. Boiling of water for drinking purposes was recommended, and no typhoid developed among families who followed the recommendation, except in those instances where members of such families drank unboiled water while at work away from home. A portion of the city is

owned by the great Harmony Knitting Mills, and is built up with tenements for their employees, of which there are many hundreds. These tenements are kept in excellent repair and the plumbing is the best in the city, but extends to kitchen sinks and drains only. No water-closets are employed, as each house is furnished with privy vault in back yard. Typhoid was especially bad in this quarter." The Cohoes Health Officer had professional occasion to visit in Waterford (population 5400) and in Lansingburgh (population 10,000), which towns are connected with Cohoes by bridges. He reported that hardly a case existed in either of those towns, and it is to be noted that one of them took water from the upper Hudson above the Mohawk junction, and the other was supplied from the hills.

West Troy (now Watervliet) is situated on the Hudson and sewers therein, but by aid of the chart it will be noticed that its water-supply came from the Mohawk some distance above Cohoes. Its population was 13,000. The following information was obtained from Dr. McNaughton, Health Officer:

"Epidemic typhoid began the last of November. At meeting of Health Board, about December 15th, fifty cases were reported. Of these, forty-two had used Mohawk water, the remainder well-water. On December 20th, the Mohawk supply was shut off and arrangements made with the town of Green Island (which village, by the way, had no fever) to use a portion of its supply. One week thereafter the weekly report of cases showed fifteen, and the second week thereafter but one case was reported. The Green Island supply was used one month. Upon returning to the Mohawk supply in the middle of January, a slight increase in typhoid was observed. Total number of cases exceeded 100. The fever, as in other places, was very mild, resulting in ten deaths."

Troy is situated directly opposite West Troy. Its population at that time was 65,000. Its water-supply came partly from lakes back in the hills, and partly from the Hudson above the Mohawk junction.

There were very few cases of typhoid in Troy during the year, and of those few a large percentage were imported from Schenectady and West Troy.

Troy dumped 8,000,000 gallons of sewage into the Hudson daily.

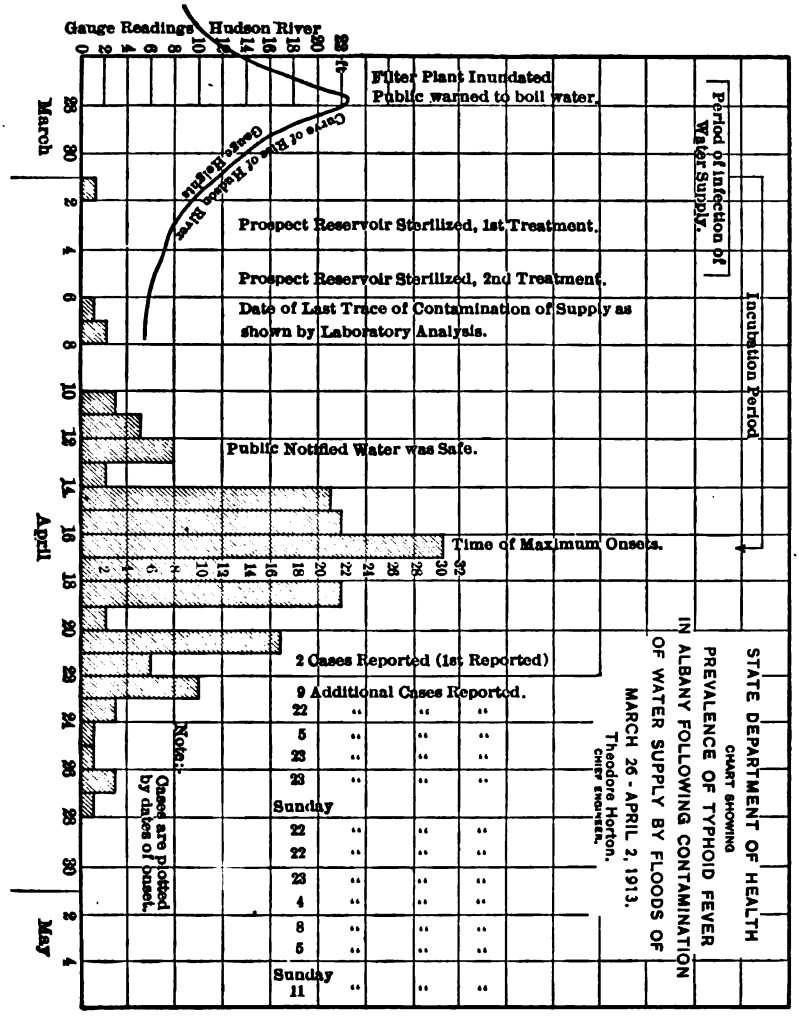
Six miles below Troy is the city of Albany; population, 100,000. Albany, at the time of the epidemic, took its water through an intake in the side of the wharf, directly in front of the city. Not only did sewage from the upper Hudson and Mohawk flow toward it, but during flood tide and south wind the return of its own sewage from the sewer outfalls below had been proven by the floating of buoys.

The typhoid epidemic began in Albany the last of December, 1890. The disease was mild in character, resulting in sixty-two deaths during the months of January, February, and March, 1891. The total number of typhoid cases reported during the same period was 411, but this figure was known to have been unreliable. Albany experienced a very serious epidemic during the winter of 1890–91, and the alarm was widespread, of that there can be no question. A small portion of the city receives its water-supply from an inland gravity source. Typhoid was not nearly so plenty in that section, only eighteen cases having been reported to the end of March.

At Van Wie's point, four miles below Albany, the laborers employed in cutting ice for the great ice-houses had typhoid fever break out among them during January. They used river-water for drinking purposes.

A more recent typhoid epidemic occurred at Albany following the great flood in the Hudson River which submerged and threw out of commission the municipal filter, thereby filling the entire water-supply system with raw river water.

The river rose very rapidly to an unprecedented height on March 26th, 27th and 28th, 1913, overtopping the filtration plant. Throughout the middle of the following month the city was visited by a pronounced outbreak of typhoid fever which began about April 10th, reached its climax on the 16th and then diminished as rapidly as it rose. In all there were about 180


STATE DEPARTMENT OF HEALTH
CHART SHOWING
PREVALENCE OF TYPHOID FEVER
IN ALBANY FOLLOWING CONTAMINATION
OF WATER SUPPLY BY FLOODS OF
MARCH 26 - APRIL 2, 1913.
Theodore Horton,
CHIEF ENGINEER.
Gauge Readings Hudson River
Curve of Rise of Hudson River
Cases Related
Filter Plant Inundated
Public warned to boil water.
Period of Infection of Water Supply.
Incubation Period
Prospect Reservoir Sterilized, 1st Treatment.
Prospect Reservoir Sterilized, 2nd Treatment.
Date of Last Trace of Contamination of Supply as shown by Laboratory Analysis.
Public Notified Water was Safe.
Time of Maximum Onsets.
2 Cases Reported (1st Reported)
9 Additional Cases Reported.
Sunday
Sunday
Note:
Cases are plotted by dates of onset.
March
April
May

cases. The average period of incubation may be placed at sixteen days.

Immediately upon the flooding of the filter the people were notified to boil their drinking water and arrangements were also made to disinfect the reservoirs upon the hills with "chloride of lime." This disinfection was accomplished very promptly, even before the early cases of the fever began to appear, but of course, it could not protect against the infection of the first few days.

Had the warning to "boil the drinking water" been heeded the epidemic might have been avoided, but the public is always slow to take such precaution. The physicians also were slow in recording their cases: "In other words the epidemic had largely disappeared before the cases had begun to be reported." *

This epidemic furnished incidental demonstration of how great a service the filter plant is daily doing in protecting the people against the danger of upstream sewage pollution.

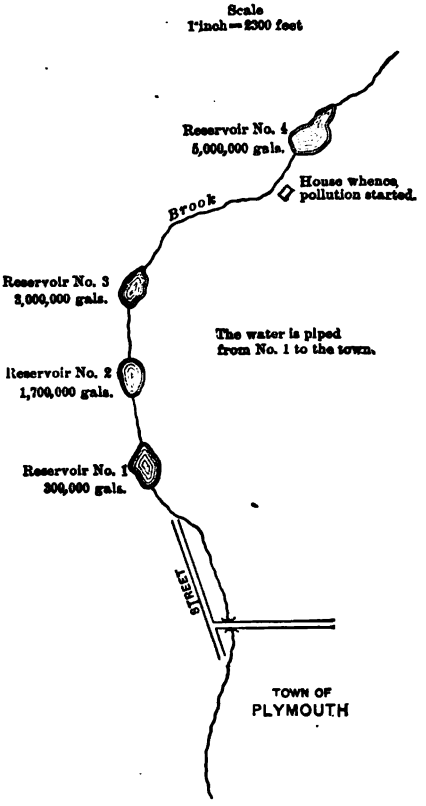
An important case of typhoid outbreak is added to those given, because, though often quoted, and doubtless familiar to most readers, the lesson it teaches is too valuable to risk losing it from the memory. The description is in part by Dr. E. F. Smith:

The city of Plymouth, Pa., contained in 1885 a population of about 8000. In this small community within a period of a few weeks there were 1104 cases and 114 deaths from typhoid fever. The epidemic was studied on the spot by competent New York and Pennsylvania physicians, so that no doubt is left either as to the nature of the disease nor as to the method of its introduction and spread.† The facts, sifted and tested by rigid and expert scientific methods, are as follows: The general water-supply of Plymouth is obtained from a mountain brook, a number of dams being thrown across the stream for the purpose of securing reservoir storage, as shown by the

* Bulletin N. Y. State Dept. Health, May, 1913.

† "Report upon the Epidemic of Typhoid Fever at Plymouth, Pa." By Lewis H. Taylor, M.D., of Wilkesbarre, Pa.

following map. During part of the winter of 1884–5, owing to the deep freezing of this stream, the hydrant water was taken from the neighboring river, Susquehanna. There are very few houses on the banks of the mountain brook, and



SKETCH MAP ILLUSTRATING THE TYPHOID FEVER EPIDEMIC AT PLYMOUTH, PA.

Reduced from report of Pennsylvania State Board of Health, 1885.

it would seem that the stream is unusually well protected from sources of contamination. On January 2, 1885, during the time that the stream was frozen, a man came from Philadelphia ill of typhoid fever. He had contracted the disease at a place from which three other persons, ill of fever, had been removed to the hospital. This man was cared for

in a house near the stream and just below Reservoir No. 4. The discharges from the bowels of the ill man were not disinfected. They were thrown by the nurse on the deep snow of a side hill sloping toward the stream which was not over forty feet distant. A sudden rise in the temperature on the 26th of March caused a general thaw, and the melted snow of the hillside with its mass of typhoid dejecta, the accumulation of nearly three months, was swept into the stream. At just this time, owing to the rise of the water in the brook and reservoir, the Susquehanna river-water was shut off from the water-mains, and that of the brook turned on again. In this way the polluted water was pumped to all parts of the city. In about two or three weeks hundreds of cases of fever developed, and these were confined exclusively to persons who used the hydrant water. No cases were traceable to well-water except much later, and by secondary infection. Whole groups of families using well-water or river-water exclusively escaped entirely. In parts of the city where the use of well-water was the rule and the use of hydrant water the exception only those families suffered which used the latter. One notable instance is mentioned by Dr. Taylor where in the upper end of the city one family only suffered from the disease. It was supposed at first that all in that vicinity used well-water, but further inquiry showed this one family to have been in the habit of catching and using the hydrant water which leaked from the main aqueduct on its way down into the city, preferring the supposedly pure water of the mountain stream to that of the foul wells of the neighborhood.

"The epidemic continued with diminished virulence on through the Spring and Summer.

"The chief peculiarity of the epidemic was the gravity of the earlier cases. As one medical man expressed it, the earlier patients seemed brimful of the poison. From the 10th to the 20th of April nearly every patient had violent delirium and a very high temperature; after that the epidemic seemed to settle down into more regular typhoid fever." *

* Pa. State Board of Health Report, 1885.

This change in virulence is most instructive and points at once to the concentrated doses of fresh infective material delivered to the early cases.

Sundry data of the epidemic:

Cases in April.....	713	Cases in May....	261
Cases in June.....	83	Cases in July.....	31
Cases in August...	15	Cases in September	1
			1104

Average age of those who died.....	24 years
Average length of illness of those who died...	23 days
Average length of illness of those recovered..	58 days
Fatality rate.....	$10\frac{1}{3}\%$

The cost of this outbreak, in actual cash, is fortunately well established, and is deserving of attention by those charged with the care of the public health. It is itemized as follows:

Loss of wages for those who recovered.	$30,020.08
Care of the sick.....	67,100.17
Yearly earnings of those who died....	18,419.52

It should be noted here that a "spot-map" of an epidemic of "water-borne typhoid" shows the "spots" distributed evenly over the city. This would be expected as the water bearing the disease is delivered to all the people. (See next page.)

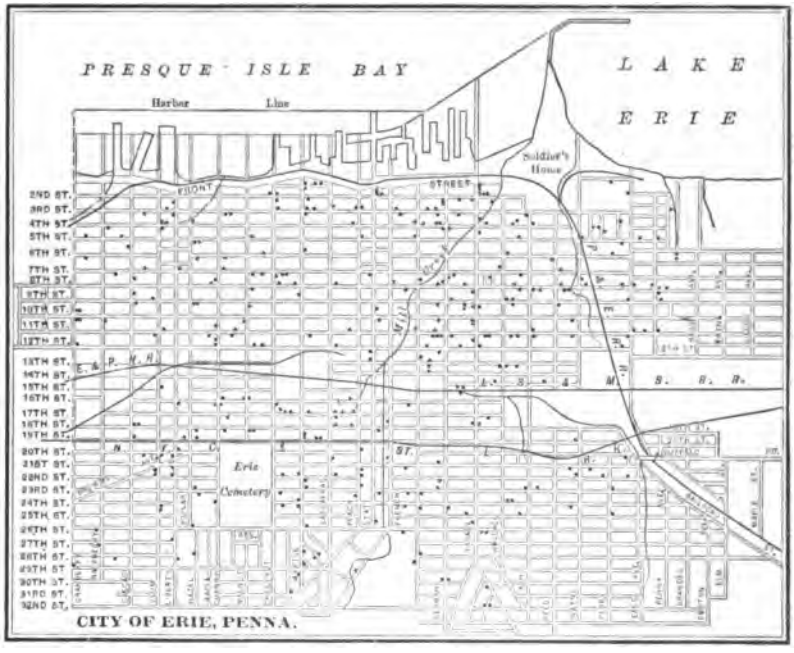
Very similar to the Plymouth outbreak was that at New Haven during the first part of 1901. Up to April there had been 315 cases reported.

"In the remote limits of an adjoining town, eight miles from New Haven, there had been during the first three months of the year, at different times, three cases of typhoid. The discharges from the patients were not disinfected.

"During the illness of these patients the ground was frozen solid, and there is every reason to believe that there was no true burial of the feces. The alleged place of burial was on a

side hill with a steep inclination to a watercourse leading directly to Dawson Lake, an important reservoir of the New Haven Water Company."

When it is remembered that much of the Chicago sewage flowed into Lake Michigan, and that until recently the intakes



SPOT MAP SHOWING EVEN DISTRIBUTION OF CASES DURING TYPHOID FEVER EPIDEMIC, 1911.

(Report of Com. Health, Pa., 1911.)

supplying the city with the lake-water were situated only a few hundred feet off shore, a comparison of the typhoid death-rates per 100,000 inhabitants for periods of five years before and after the driving of the four-mile tunnel is suggestive.* The tunnel was opened December 3, 1892.

Average for the years 1888 to 1892 inclusive	96.9
" " " 1893 to 1897 "	42.1

* Bul. Chicago Health Depart., May 27, 1905.

Much as the new tunnel did for Chicago, the difficulty was not entirely remedied, for the reason that sewage occasionally reached the four-mile crib until after the opening of the Drainage Canal, which caused it to flow into the Illinois River.

As a measure of the betterment in the quality of the lake water resulting from the opening of the canal, let the following facts, taken from the Bulletin of the Department of Health of Chicago for May 19, 1906, speak for themselves: "During the six years immediately preceding the opening of the drainage channel there had been a total of 141,473 deaths in Chicago, an average of 23.579 each year, a rate of 16.2 per thousand of the population. During the subsequent six years, ending December 31, 1905, there was an annual average of 26,373 deaths, a rate of 14.31 per thousand, or a reduction of 11.7 per cent in the general mortality.

"Deaths from typhoid fever in the pre-channel period were 3275, an annual rate of 37.6 per 100,000 population. Deaths from typhoid fever during the channel period were 2937, an annual rate of 26.9 per 100,000 population, a reduction of 29 per cent.

"Deaths from diarrhœal diseases in the pre-channel period 16,669, an annual rate of 192.9 per 100,000 population. Deaths from diarrhœal diseases during the channel period 13,609, an annual rate of 123.1 per 100,000 population, a reduction of 36.9 per cent.

"The total cost of the channel up to December 31, 1905, had been less than 50 million dollars.

"The figures given above of typhoid-fever and diarrhœal-diseases mortality show a constructive or potential saving of 8966 lives, which, at the legislative valuation, represents a total of $89,660,000."

It will be noted from the foregoing that typhoid fever is not the only disease that is diminished by an improved water supply but that the general group of intestinal disorders responds as well. This point is well illustrated in a paper by M. N. Baker, read before the New England Water Works Association.*

* J. N. E. Water Works Asso., xx. 163.

Whipple also enlarges upon the same proposition, as will be seen from the following table where comparison is made between the rates in Albany, both before and after filtration, and those in Troy, where no filtration is used, during the same periods.*

ALBANY (BEFORE AND AFTER FILTRATION)

Average Annual Rates per 100,000 Population.	1894–98	1900–04	Difference.	Reduction as Per Cent.
Typhoid fever	104	26	78	75
Diarrhœal diseases	125	53	72	57
Children under five years	606	309	297	49
Total deaths	2246	1868	378	17

TROY (SAME PERIOD, NO FILTRATION)

Average Annual Rates per 100,000 Population.	1894–98	1900–04	Difference.	Reduction as Per Cent.
Typhoid fever	57	57	0	0
Diarrhœal diseases	116	102	14	12
Children under five years	531	435	96	18
Total deaths	2157	2028	129	6

TABLE SHOWING IMPROVEMENT IN DEATH-RATES FROM TYPHOID FEVER IN MASSACHUSETTS

Years.	Deaths per 100,000 Inhabitants.
1871–75	82
1876–80	42
1881–85	41
1886–90	46
1891–95	34
1896–1900	26
1901–05	19
1906–10	13.8
1911–15	7.6

* J. New England Water Works Asso., xix. 461.

TYPHOID FEVER DEATH-RATES PER 100,000 POPULATION, IN CITIES OF THE UNITED STATES OF OVER 100,000 POPULATION*

City.	Population 1910	Average for 1900–1905, incl.	1906	1907	1908	1909	1910	1911	1912	Source of Water-supply.	Purification of Water-supply.‡
Allegheny, Pa.†	150,000	107	136	97	40	28	42	39	9	Allegheny River	Sterilization
Albany, N. Y.	100,253	25	20	20	11	19	15	18	18	Hudson River	Slow sand filtration
Atlanta, Ga.	154,839	65	50	64	47	44	43	56	35	Chattahooche River	Rapid sand filtration
Baltimore, Md.	558,845	36	34	41	31	23	42	26	22	Gunpowder Cr. and Jones Falls	Sterilization
Birmingham, Ala.	132,685	50	39	71	64	44	51	44	38	Cahaba River	Rapid sand filtration
Boston, Mass.	680,585	23	22	10	26	14	11	8	9	Impounded streams	None
Bridgeport, Conn.	102,054	15	10	13	13	13	9	4	8	Poland River impounded	None
Buffalo, N. Y.	423,715	29	24	29	21	23	20	25	11	Lake Erie	None
Cambridge, Mass.	104,839	18	18	10	10	9	12	4	4	Impounded streams	None
Chicago, Ill.	2,185,283	27	18	18	15	12	14	10	7	Lake Michigan	One-fourth sterilized
Cincinnati, O.	363,591	54	71	46	19	13	6	11	7	Ohio River	Rapid sand filtration
Cleveland, O.	560,663	51	20	19	13	12	19	14	6	Lake Erie	Sterilization
Columbus, O.	181,511	61	45	38	110	17	17	14	19	Scioto River	Rapid sand filtration
Dayton, O.	116,577	29	28	38	16	24	18	18	17	Driven wells	None
Denver, Colo.	213,381	37	68	67	58	24	28	17	13	Platte River and Marston Lake	Infiltration galleries, slow and
Detroit, Mich.	465,766	17	22	28	22	19	20	16	19	Lake St. Clair	None rapid sand filters
Fall River, Mass.	119,295	19	8	18	13	14	13	15	16	No. Wattupa Pond	None
Grand Rapids, Mich.	112,571	34	39	30	30	17	26	25	31	Grand River	Rapid sand filtration
Indianapolis, Ind.	233,650	76	39	29	26	22	30	26	17	White River and wells	Slow sand filtration
Jersey City, N. J.	267,779	19	20	14	10	8	12	8	8	Rockaway River impounded	Sterilization
Kansas City, Mo.	248,381	48	38	40	35	23	43	24	12	Missouri River	Sterilization
Los Angeles, Cal.	319,198	35	18	23	19	18	12	13	12	Los Angeles River and wells	Infiltration galleries
Louisville, Ky.	223,928	55	63	79	49	43	31	25	19	Ohio River	Rapid sand filtration
Lowell, Mass.	106,294	19	7	9	24	11	21	6	9	Driven wells	None
Memphis, Tenn.	131,105	37	39	35	33	41	28	61	56	Wells	None
Milwaukee, Wis.	373,859	19	31	26	17	21	46	19	23	Lake Michigan	Sterilization
Minneapolis, Minn.	301,408	38	33	26	18	20	58	11	11	Mississippi River	Sterilization
Nashville, Tenn.	110,364	54	66	85	62	53	48	51	29	Cumberland River	Coagulation-sedimentation
Newark, N. J.	347,469	17	18	24	12	11	13	10	7	Pequannock River impounded	None
New Haven, Conn.	133,605	44	54	30	34	20	18	23	24	Lakes	Slow sand filtration (Lake Whit-
New Orleans, La.	339,075	40	30	56	31	25	32	30	13	Mississippi River	Rapid sand filtration ing only)
New York, N. Y.	4,766,883	19	15	17	12	12	12	11	10	Croton River impounded	Sterilization
Oakland, Cal.	150,174	19	26	28	18	7	13	13	19	Impounded	Rapid sand filtration
Omaha, Neb.	124,096	20	28	24	22	31	89	17	12	Missouri River	Sedimentation and sterilization
Paterson, N. J.	125,600	25	4	11	10	5	7	5	7	Passaic River	Rapid sand filtration
Philadelphia, Pa.	1,549,008	47	74	60	36	22	17	14	12	Delaware and Schuylkill Rivers	Slow sand filtration
Pittsburgh, Pa.†	410,000	132	141	135	53	13	12	10	6	Allegheny River	Slow sand filtration
Portland, Ore.	207,214	..	25	33	24	20	23	18	17	Bull Run River	None
Providence, R. I.	224,326	20	19	8	16	12	17	14	10	Pawtucket River	Slow sand filtration
Richmond, Va.	127,628	66	44	41	50	24	22	17	15	James River	Coagulation-sedimentation
Rochester, N. Y.	218,149	15	17	16	12	9	14	11	12	Hemlock Lake	None
St. Louis, Mo.	687,029	33	18	16	15	15	13	10	13	Mississippi River	Coagulation-sedimentation
St. Paul, Minn.	214,744	14	21	17	12	20	20	10	9	Lake and artesian wells	None
San Francisco, Calif.	416,912	20	..	57	27	17	15	16	14	Impounded	Filtration—aeration
Scranton, Pa.	129,867	18	11	76	11	11	14	12	9	Impounded	Rapid sand filtration
Seattle, Wash.	237,194	..	20	48	22	23	14	10	8	Cedar Lake and River	None
Spokane, Wash.	104,402	..	47	38	40	32	32	37	17	Dug wells	None
Syracuse, N. Y.	137,249	14	10	16	15	12	28	15	16	Skaneateles Lake	None
Toledo, O.	168,497	36	45	36	40	31	37	22	31	Maumee River	Rapid sand filtration
Washington, D. C.	331,069	59	52	36	39	33	25	22	23	Potomac River	Slow sand filtration
Worcester, Mass.	145,986	17	12	14	10	8	16	7	3	Brooks and pond	None

* Compiled by Geo. A. Johnson. † Allegheny and Pittsburgh are now combined in Greater Pittsburgh. ‡ The rapid sand filtration plant at Atlanta, Ga., is of the pressure type; all the other rapid filters are of the gravity type.

HEALTH STATUS OF THE WORLD'S LEADING CITIES FOR THE YEAR 1912 *

City.	Population.	General Death Rate per 1000 of Pop.	Typhoid Fever Death-Rates per 100,000 of Pop.
London (proper)	4,519,754	13.6	3
New York	5,173,064	14.1	10
Paris	2,872,128	16.3	9
Chicago	2,294,711	14.8	8
Berlin	2,083,391	14.4	2
Vienna	2,081,335	15.4	2
St. Petersburg	1,664,000	21.9	50
Moscow	1,640,900	24.3	12
Philadelphia	1,606,105	15.1	12
Buenos Aires	1,381,318	16.6	47
Bombay	979,445	39.8	..
Hamburg	975,562	13.6	3
Rio de Janeiro	946,134	21.3	6
Budapest	910,548	18.5	11
Calcutta	896,067	28.1	..
Brussels	745,380	13.5	7
Boston	720,031	16.2	8
Cairo	704,956	37.4	..
Sydney	674,500	11.4	9
Milan	615,375	15.8	..
Munich	615,000	14.7	1
Melbourne	614,300	14.0	5
Leipzig	605,755	12.7	1
Amsterdam	584,416	11.2	3
Rome	572,099	14.0	..
Baltimore	569,561	18.3	..
Dresden	559,700	13.1	3
Cologne	532,000	14.4	2
Breslau	530,000	18.4	2
Madras	518,660	38.7	..

In the State of Connecticut the typhoid statistics for the past forty-three years show a continual improvement, which must be due, at least in part, to abolition of old private wells for new and better water-supply. The number of deaths (for the entire State) from typhoid per 100,000 population stands as follows:†

* Bulletin Chicago School of Sanitary Instruction.

† See Board of Health Reports.

Average for the five years	1865–69	83
" " "	1870–74	75
" " "	1875–79	54
" " "	1880–84	42
" " "	1885–89	34
" " "	1890–94	35
" " "	1895–99	22
" " "	1900–04	24
" " "	1905–09	19
" " three"	1910–12	14

Statistics compiled for the Massachusetts Board of Health by Mr. H. F. Mills * show how greatly the typhoid death-rate is improved in towns by a change from the domestic well system to that of a public supply.

CHANGE IN THE DEATH-RATE FROM TYPHOID FEVER PER 100,000 INHABITANTS IN CITIES OF MASSACHUSETTS WHICH INTRODUCED WATER-SUPPLIES FROM 1867 TO 1876

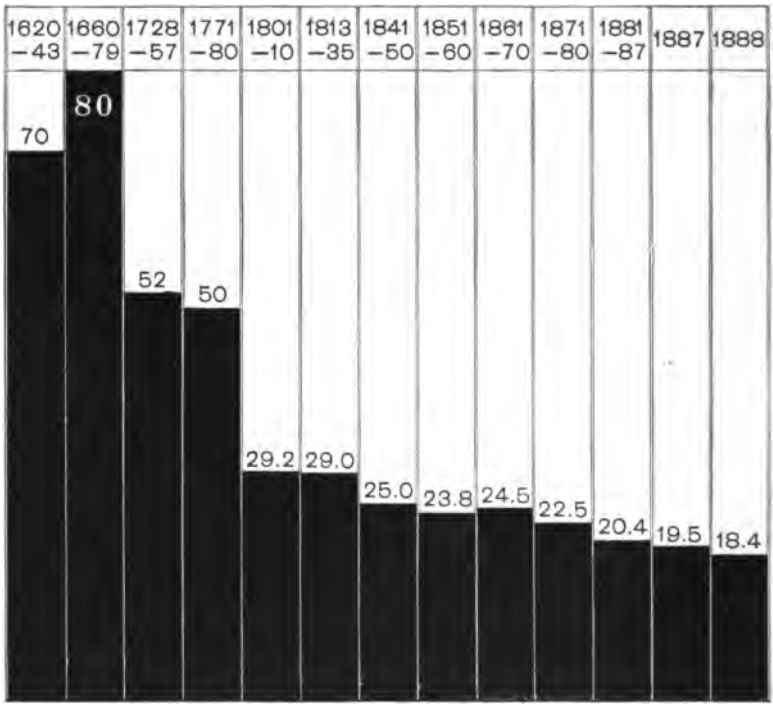
	Annual Average, 1859–68.	Date of Water-supply.	Annual Average. 1878–89.	Per Cent of Average.
Fall River	77.8	1874	63.2	81
Springfield	96.7	1875	52.9	55
Taunton	61.2	1876	50.2	82
Northampton	109.8	1871	40.4	37
Lynn	90.6	1871	38.7	43
New Bedford	77.7	1869	38.0	49
Newton	65.7	1876	36.5	56
Malden	80.4	1870	35.4	44
Fitchburg	105.9	1872	31.6	30
Woburn	82.9	1873	29.5	36
Somerville	42.8	1867	29.5	69
Chelsea	59.7	1867	28.9	48
Waltham	81.2	1873	24.2	30
Average	79.4		38.3	

The advance along sanitary lines shown by the foregoing data is encouraging, and it effectually answers the frequently recurring question, " How was it our fathers got along so well without all these so-called modern improvements? "

* Mass. Board of Health, 1890.

Figures such as those given, and others like them that might be quoted, stand in evidence that the question is a begged one, and that our progenitors were not so well off as many people fancy.

In illustration of this point, it is instructive to note the improvement in the general death-rate of London.



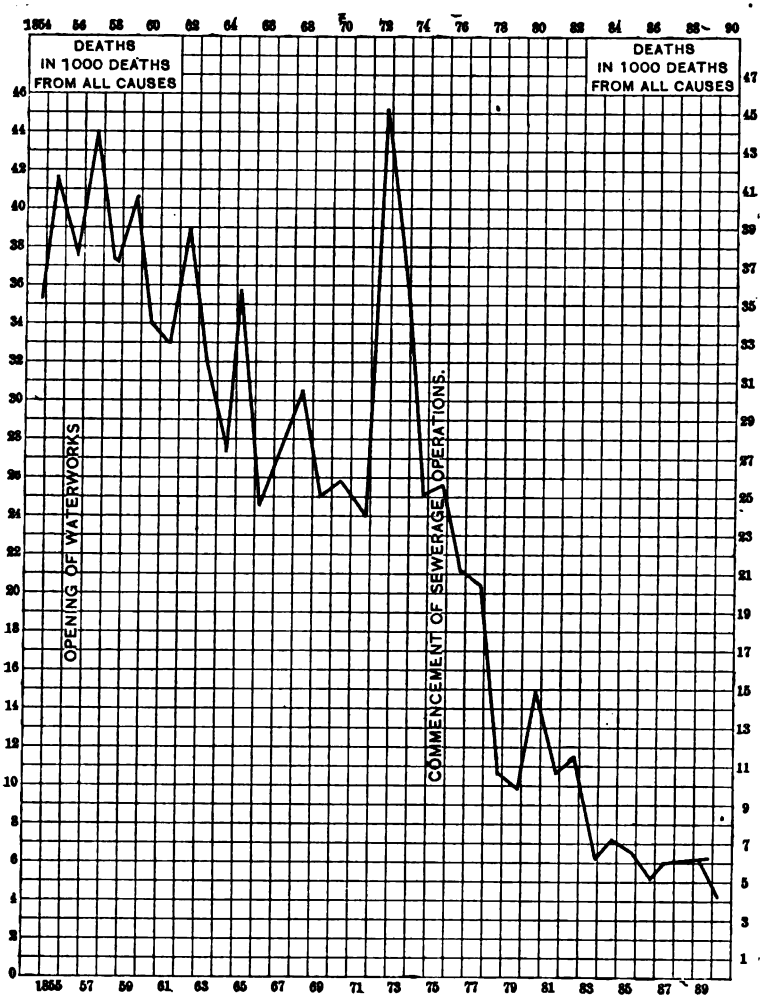
DEATHS IN LONDON FROM ALL CAUSES PER 1000 POPULATION PER ANNUM IN PERIODS REPRESENTING THE 17TH, 18TH, AND 19TH CENTURIES.

(From report of State Board of Health, Michigan.)

Improvement in the general death-rate per year for New York City per 1000 population is shown by the following:

	Death-rate per 1000
1872	30.96
1882	28.06
1892	25.38
1902	18.58
1912	14.11

There is no question but that sanitary betterments show widespread effect upon the general death-rates. During the



TYPHOID MORTALITY IN BERLIN (ROECHLING).

past thirty years the improvement for ten of the world's largest cities averages 31.1 per cent.*

* See U. S. Census Bul., 109.

In this connection it is interesting to observe the increase in the median age of the population of the United States.*

1850	18.28 years
1860	18.87 "
1870	19.65 "
1880	20.45 "
1890	21.38 "
1900	22.3 (estimated)

It might be well to note that water-supply systems should not be introduced into country towns until arrangements have been made to care for the necessarily increased volume of sewage thereby produced; otherwise the old vaults may become overloaded and carry pollution to greater distances than it went before, thus damaging the remaining wells.

As showing the exceeding difference between care and no care in the selection of water for potable supply, the following quotation is taken from a report by Dr. Simmons, of the Yokohama Board of Health, covering certain features of the water question in India:

"The drinking-water supply is derived from wells, so-called 'tanks' or artificial ponds, and the watercourses of the country. The wells generally resemble those in other parts of Asia. The tanks are excavations made for the purpose of collecting the surface-water during the rainy season and storing it up for the dry. Necessarily they are mere stagnant pools. The water is used not only to quench thirst, but is said to be drunk as a sacred duty. At the same time, the reservoir serves as a large washing-tub for clothes, no matter how dirty or in what soiled condition, and for personal bathing. Many of the watercourses are sacred: notably the Ganges, a river 1600 miles long, in whose waters it is the religious duty for millions, not only for those living near its banks, but of pilgrims, to bathe and to cast their dead. The Hindoo cannot be made to use a latrine. In the cities he digs a hole

* Merriman's "Sanitary Engineering" (1899), page 43.

in his habitation; in the country he seeks the fields, the hill-sides, the banks of streams and rivers when obliged to obey the calls of nature. Hence it is that the vicinity of towns and the banks of the tanks and watercourses are reeking with filth of the worst description, which is of necessity washed into the public water-supply with every rainfall. Add to this the misery of pilgrims, their poverty and disease, and their terrible crowding into the numerous towns which contain some temple or shrine, the object of their devotion, and we can see how India has become and remains the hot-bed of the cholera epidemic. In the United States official report, the horrors incident upon the pilgrimages are detailed with appalling minuteness. W. W. Hunter, in his Orissa, states that twenty-four high festivals take place annually at Juggernaut. At one of them, about Easter, 40,000 persons indulge in hemp and hasheesh to a shocking degree. For weeks before the car festival in June and July, pilgrims come trooping in by thousands every day. They are fed by the temple cooks to the number of 90,000. Over 100,000 men and women, many of them unaccustomed to work or exposure, tug and strain at the car until they drop exhausted and block the road with their bodies. During every month of the year a stream of devotees flows along the great Orissa road from Calcutta, and every village for three hundred miles has its pilgrim encampments. The people travel in small bands, which at the time of the great feasts actually touch each other. Five-sixths of the whole are females, and ninety-five per cent travel on foot, many of them marching hundreds and even thousands of miles, a contingent having been drummed up from every town or village in India by one or other of the three thousand emissaries of the temple, who scour the country in all directions in search of dupes. When those pilgrims who have not died on the road arrive at their journey's end, emaciated, with feet bound up in rags and plastered with mud and dirt, they rush into the sacred tanks or the sea, and emerge to dress in clean garments. Disease and death make havoc with them during their stay; corpses are buried in holes scooped in the

sand, and the hillocks are covered with bones and skulls washed from their shallow graves by the tropical rains. The temple kitchen has the monopoly of cooking for the multitude, and provides food which, if fresh, is not unwholesome. Unhappily, it is presented before Juggernaut, so becoming too sacred for the minutest portion to be thrown away. Under the influence of the heat it soon undergoes putrefactive fermentation, and in forty-eight hours much of it is a loathsome mass, unfit for human food. Yet it forms the chief sustenance of the pilgrim, and is the sole nourishment of thousands of beggars. Some one eats it to the very last grain. Injurious to the robust, it is deadly to the weak and wayworn, at least half of whom reach the place of suffering under some form of bowel complaint. Badly as they are fed, the poor wretches are worse lodged. Those who have the temporary shelter of four walls are housed in hovels built upon mud platforms about four feet high, in the centre of each of which is the hole which receives the ordure of the household, and around which the inmates eat and sleep. The platforms are covered with small cells without any windows or other apertures for ventilation, and in these caves the pilgrims are packed, in a country where, during seven months out of the twelve, the thermometer marks from 85° to 100° Fahr. Hunter says that the scenes of agony and suffocation enacted in these hideous dens baffle description. In some of the best of them, 13 feet long by 10 feet broad and $6\frac{1}{2}$ high, as many as 80 persons pass the night. It is not, then, surprising to learn that the stench is overpowering and the heat like that of an oven. Of 300,000 who visit Juggernaut in one season, 90,000 are often packed together for a week in 5000 of these lodgings. In certain seasons, however, the devotees can and do sleep in the open air, camping out in regiments and battalions, covered only with the same meagre cotton garment that clothes them by day. The heavy dews are unhealthy enough; but the great festival falls at the beginning of the rains, when the water tumbles in solid sheets. Then lanes and alleys are converted into torrents or stinking canals, and the pilgrims are driven into the vile tenements.

Cholera invariably breaks out. Living and dead are huddled together. In the numerous so-called corpse-fields around the town as many as forty or fifty bodies are seen at a time, and vultures sit and dogs lounge lazily about gorged with human flesh. In fact, there is no end to the recurrence of incidents of misery and humiliation, the horrors of which, says the Bishop of Calcutta, are unutterable, but which are eclipsed by those of the return journey. Plundered by priests, fleeced by landlords, the surviving victims reel homeward, staggering under their burden of putrid food wrapped up in dirty clothes, or packed in heavy baskets or earthenware jars. Every stream is flooded, and the travellers have often to sit for days in the rain on the bank of a river before a boat will venture to cross. At all these points the corpses lie thickly strewn around (an English traveller counted forty close to one ferry), which accounts for the prevalence of cholera on the banks of brooks, streams, and rivers. Some poor creatures drop and die by the way; others crowd into the villages and halting-places on the road, where those who gain admittance cram the lodging-places to overflowing, and thousands pass the night in the streets, and find no cover from the drenching storms. Groups are huddled under the trees; long lines are stretched among the carts and bullocks on the roadside, their hair saturated with the mud on which they lie; hundreds sit on the wet grass, not daring to lie down, and rocking themselves to a monotonous chant through the long hours of the dreary night. It is impossible to compute the slaughter of this one pilgrimage. Bishop Wilson estimates it at not less than 50,000. And this description might be used for all the great Indian pilgrimages, of which there are probably a dozen annually, to say nothing of the hundreds of smaller shrines scattered through the peninsula, each of which attracts its minor hordes of credulous votaries. So that cholera has abundant opportunities for spreading over the whole of Hindostan every year by many huge armies of filthy pilgrims; and the country itself well deserves the reputation it universally possesses of being the birthplace and settled home of the malady."

With the Chinese it is quite different. "Although their country is in closest proximity to India, and of much greater extent and twice as populous, you will find that cholera is comparatively rare. The drinking-water supply of China is derived from wells, springs, and natural streams. Now, though the wells and springs are used in China for drinking purposes to much the same extent and in much the same manner as in India, yet the rivers and lakes are not drunk from as a part of a religious duty, nor is bathing in them a sacred rite. The absence of pilgrimages contributes to keep the water comparatively uncontaminated.

"Human manure is valuable and hoarded for fertilizing purposes. Hence the excreta are deposited by the individual in a receptacle made for the express purpose, and from motives of economy kept in a fairly good condition of repair. Even in cities and large towns latrines are not employed. Special wooden boxes are among the first necessities of bedroom furniture, and form part of every bridal outfit. The contents are daily emptied into earthen jars or wooden tubs placed in the court-yard of the house, whence they are removed by the scavenger either direct to the fields, or to boats destined to convey them to a distance. Thus the greatest amount of security attainable is provided against the contamination of the water-supply from this source. A still more potent preventive of infection is to be found in the fact that the Chinese will always, if possible, boil water before drinking it, even if they are unable to make it into some kind of tea. Here it is easy to see, in the contrast between the customs of the Hindoo on the one hand and the Chinese on the other, how in the one case every possible facility is provided for the propagation of infection; in the other, how the danger of contamination is reduced to a minimum."

This statement concerning China is hardly in accord with the following naval report:

"In Japan and China the close relation of the food and water supply with the excreta not only illustrates the ætiology of cholera, but, at the same time, shows what small prospect

there is of its extermination. In Japan the soil is tilled in absolute contiguity to the wells, and is fertilized with liquefied human excreta. Dr. Jameson, a physician of Shanghai, cites an instance where, under a spigot, he saw the rice for the daily food being washed at the same time with a vessel just emptied of cholera discharges." *

Illustrations such as have been given, showing the power of water to carry specific disease, could be very greatly multiplied. J. W. Hill has published a list of cases of this character in "J. Am. Water-works Asso.," 1897, 168; Wilson's "Handbook of Hygiene" furnishes a further number, notably the celebrated "Broad Street well case"; the widely known report of the epidemic at Lausen, Switzerland, will be found in "Nature," xiii, 447; while a historic summary of two hundred and five outbreaks of "water-borne typhoid" in Great Britain has been published by E. Hart, in a report prepared for the Parliamentary Bills Committee of the British Medical Association, 1897. It would not be wise to devote space to these cases beyond the reference given, but it is well to pause for a moment to consider what may be learned from the terrible outbreak of cholera at Hamburg, Germany, in 1892.

The city had at that time a population of 640,400. In the official tabulation the epidemic is noted as having lasted from August 16th to November 12th, although 42 deaths appear to have taken place in the next month (December) and 20 in January, 1893. The total number of cholera cases reported during that time was 17,020, with a total death-list of 8605, a mortality percentage of 50.05.

By months the cases were:

August.....	7,427	December....	42
September.....	9,341	January.....	20
October.....	181	February.....	1
November.....	7	March.....	1
			17,020

* Report of Surgeon-General U. S. Navy, 1892.

To a proper appreciation of the conditions of this epidemic a study of the local map is essential.

It will be observed that Altona (143,000 population), Hamburg (640,400 population), and Wandsbeck (20,000 pop-

AFTER REINKE AND SEDGWICK.

ulation) are practically one and the same town, separated by only imaginary boundaries, which a stranger could not locate. The three municipalities are, however, supplied with water from three different sources. Wandsbeck obtains filtered water from a lake unexposed to contamination; Hamburg

pumps water from the Elbe River, and in 1892 the intake was situated just south of the city, but not far enough up-stream to escape contamination from a recession of polluted water at flood-tide. After some imperfect sedimentation, the water passed directly to the consumer without filtration. Altona, strangely enough, pumps its water from the Elbe at a point about eight miles below that at which the river receives the combined sewage of the three cities, with their population of over 800,000. Fortunately for Altona, this most grossly polluted supply is filtered with exceeding care before delivery to the people. Further description of the Hamburg epidemic can best be given in the words of Dr. Thorne, medical officer of the London Local Government Board: *

" The different behavior of Hamburg and Altona as regards cholera is extremely interesting in this connection. The two towns adjoin; they are practically one city. The division between the two is no more obvious than that between two densely peopled London parishes, and yet a spot-map indicating the houses which were attacked with cholera, which was shown to me by Professor Koch, points out clearly that whereas the disease prevailed in epidemic form on the Hamburg side of the boundary line, that line, running in and out among the streets and houses and at times passing diagonally through the houses themselves, formed the limit beyond which the epidemic as such did not extend. The dots on one side of the dividing line were proof of the epidemicity of cholera in Hamburg; their comparative absence on the Altona side of it was proof of the absence of an epidemic in Altona. To use Professor Koch's own words: 'Cholera in Hamburg went right up to the boundary of Altona and there stopped. In one street, which for a long way forms the boundary, there was cholera on the Hamburg side, whereas the Altona side was free from it.' And yet there was one detectable difference, and one only, between the two adjacent areas—they had different water-services.

" Professor Koch has collected certain proofs which he

* " Cholera Prospects and Prevention," London, 1893.

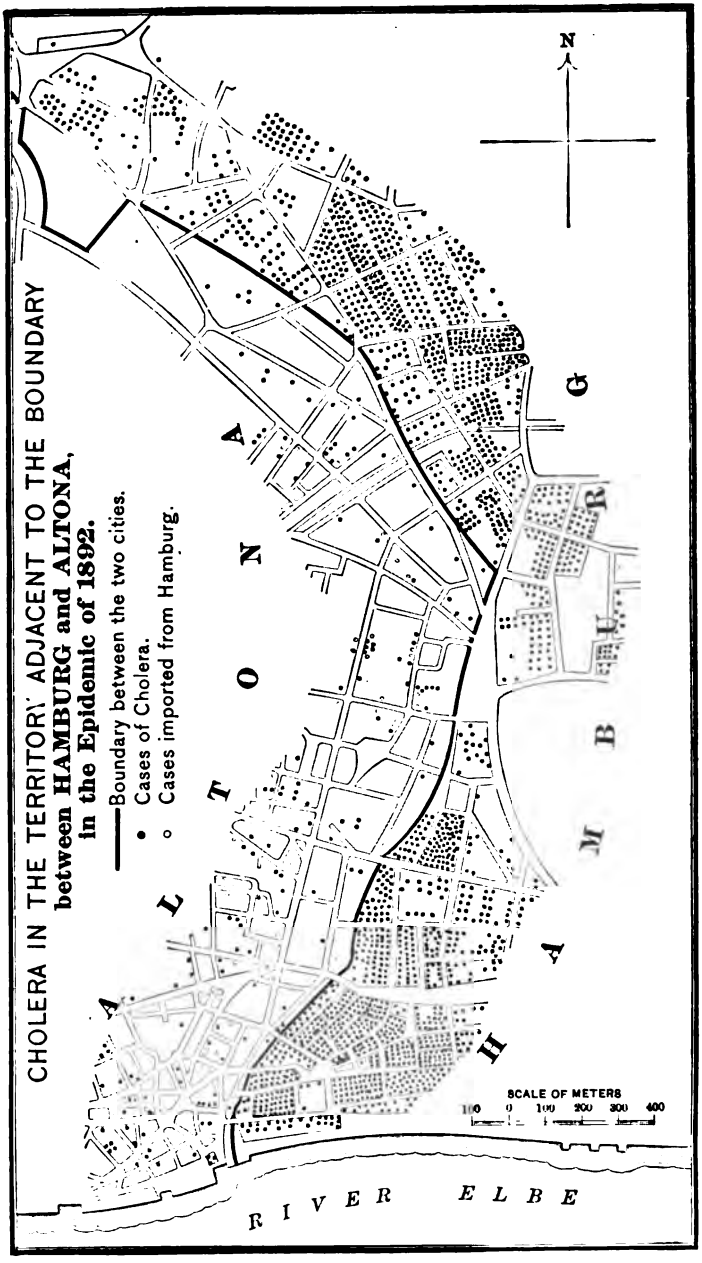


CHART SHOWING DISTRIBUTION OF CHOLERA CASES IN THE EPIDEMIC OF 1892.
(From "Filtration of Municipal Water-supply," by Rudolph Hering.)

regards as crucial on this point, and Dr. Reincke has supplied me with a small plan in support of the contention. At one point close to and on the Hamburg side of the boundary line between Hamburg and Altona is a large yard known as the Hamburger-Platz. It contains two rows of large and lofty dwellings, containing seventy-two separate tenements and some 400 people, belonging almost wholly to those classes who suffered most from cholera elsewhere in Hamburg. But whilst cholera is shown by the spot-map to have prevailed all around, not a single case occurred amongst the many residents of this court during the whole epidemic. And why? Professor Koch explains that owing to local difficulties water from the Hamburg mains could not easily be obtained for the dwellings in question, and hence a supply had been laid on from one of the Altona mains in an adjacent street. This was the only part of Hamburg which received Altona water, and I am informed that it was the only spot in Hamburg in which was aggregated a population of the class in question which escaped the cholera. At the date of my visit to Hamburg a notice-board was affixed at the entrance of this court. It stated that certain tenements were to let; but above all, in large type, and as an inducement to intending tenants, was the announcement that the court was not only within the jurisdiction of Hamburg, with the privileges still attaching to the old Hanseatic cities, but that it had a supply of Altona water."

During this epidemic the deaths in the several cities were:

	Population.	Deaths.	Deaths per 10,000 Inhabitants.
Hamburg	640,400	8605	134.4
Altona	143,000	328	23.0
Wandsbeck	20,000	43	22.0

"That infectious matter was communicated to the Elbe water from Hamburg is not in any way a hypothesis. Cholera germs had been as a fact found in the Elbe water. They

were found a little below the place where the Hamburg main sewer flows into the Elbe. They were also found in one of the two (Altona) basins into which the water flowed before filtration." *

Dr. Reincke says † in regard to Hamburg that the evidence that the reduction of typhoid in the city has been the result of an improvement in the water is substantiated by the fact that the typhoid among the shipping interests in the harbor, which use the raw water, is as great as it was before, while in the city it has fallen from 90 per 100,000 in 1887 to 6 in 1894 and 9 in 1895. In another place he argues that typhoid fever has always come through the same channels as cholera, and shows by a tabular statement that the maximum of typhoid has followed two or three weeks later than the maximum of cholera, the difference in time representing the longer incubation period of the former disease.

No invasion of cholera has yet appeared to test the efficiency of the elaborate filter-plant which Hamburg has since constructed, but the filters are certainly doing good work toward the suppression of typhoid fever.

To the man who purposes dealing with the question of public water-supply, some knowledge of the ætiology of the two prominent water-borne diseases, "cholera" and "typhoid fever," is essential to the proper and successful meeting of his professional responsibilities. These two diseases are not the only ones that are water-borne, but they are the most prominent. Dysentery, paratyphoid, diarrhœa, and sundry other disorders are on the list, but if the serious ones be guarded against the protective measures taken will serve to prevent danger from the others as well.

The cholera "germ" (*spirillum cholera Asiaticæ*), or "*comma bacillus*," was discovered by Koch in 1884 in the

* Koch, "Zeit. für Hygiene und Infect.-Krank.," xiv.

† "Zur Epidemiologie des Typhus in Hamburg und Altona," paper before the Hamburg Artz, Verein, Jan. 2, 1896; also Fuertes, "Water and Public Health."

excreta of cholera patients and in the intestinal contents of those dead of the disease.

The spirillum will grow in ordinary culture-jelly at the usual temperature, forming in twenty-four hours small white colonies which increase in size and finally entirely liquefy the gelatine. Growth is arrested if the temperature exceed 107° F., or if it fall below 59° F.

In shape it is not unlike the "comma," whence it derives its name, and the union of two or more attached end to end

CHOLERA SPIRILLUM. (After Fränkel and Pfeiffer.)
From Hiss and Zinsser's "Bacteriology." Courtesy of D. Appleton & Co.)

often causes the appearance of semicircles, S-shaped figures, and long spiral filaments. In size it varies from 0.8 to 2 microns in length, and from 0.3 to 0.4 in breadth. It is generally conceded that the cholera spirillum does not form spores, a characteristic which permits of its ready destruction by heat, a "spore" being much more difficult to destroy than a full-grown bacterium. Sternberg found the thermal death-point to be 52° C. (125.6° F.) the time of exposure having been four minutes, and, although a slightly higher figure has been recorded by other investigators, there is no question but that the degree of heat required is low.

"In a moist condition this spirillum retains its vitality for months. Koch demonstrated its presence in the foul water of a tank in India which was used by the natives for drinking purposes. It is quickly destroyed by desiccation, as first determined by Koch, who found that it did not grow after two or three hours when dried in a thin film on a glass cover." If the thickness of the film be considerable, or if the drying take place on silk threads, the vitality may remain for some weeks. (Kitasato.)

VIABILITY OF THE CHOLERA SPIRILLUM IN WATER

Babes (1884–85) found the organism alive after seven days in Seine water.

Wolffhügel (1886) found that it may live fifteen to twenty days in unsterilized tap-water. He repeatedly found it alive after three months, and believes this due to what has been termed acclimatization. Rarely the organisms die in the first few days.

Karliniski (1889) found the organism dead after two or three days in unsterilized spring-water.

Hockstetter (1887) found that the organism lives indefinitely in unsterilized tap-water even when the water contains large numbers of other organisms. He found the germs alive after an interval of 392 days.

Nicati and Rietsch (1885) found the spirillum alive in sterilized distilled water after twenty days; in sterilized water from the port of Marseilles after eighty-one days; in Marseilles canal-water, thirty-eight days; in sea-water, sixty-four days; in bilge-water from an iron steamship *en route* from Japan, thirty-two days.

According to Giaxa, cholera germs quickly died in water containing many other bacteria, and typhoid germs also died, but less quickly. Schiller found that cholera germs lived fourteen days in a mixture of excrement and urine, and for thirteen days in Berlin sewage. Cunningham found them able to live four to five days in clear water at room temperature, and in dirty water four to nine days. In the latter water,

previously boiled, they lived twenty-five days; in garden earth, ten to twenty-six days; in the same earth mixed with fecal material, six to nine days; in same mixture of earth and fæcal matter previously cooked—i.e., sterilized—forty-seven days.

Gruber and von Kerner show the power of the cholera spirillum to remain alive in river-water, and in that of the Vienna city supply, for seven days.

Christian reports that cholera organisms will live four months if frozen with slime.*

Houston found that they would die rapidly in river-water during laboratory storage. At least 99.9 per cent perished in one week and none survived three weeks.

They are more easily destroyed than typhoid bacilli under like conditions.†

These conflicting data are very confusing. The more recent ones, such as those reported by Houston, are the most reliable.

According to Boer and Bolton, the cholera spirillum is killed by a two-hours' exposure to the following solutions: hydrochloric acid, 1 : 1350; sulphuric acid, 1 : 1300; caustic soda, 1 : 150; ammonia 1 : 350; mercuric cyanide, 1 : 60,000; silver nitrate, 1 : 4000; arsenite of soda, 1 : 400; malachite green, 1 : 5000; methyl violet, 1 : 1000; carbolic acid, 1 : 400; mercuric chloride, 1 : 10,000; blue vitriol, 1 : 500

" Experiment has shown the spirillum to be very sensitive to the action of acids. Stutzer states that a solution of .05 per cent of sulphuric acid is fatal to the cholera spirillum in fifteen minutes, and a .02 per cent solution kills in twenty-four hours. He found that iron pipes could be disinfected by sulphuric acid without the metal being sensibly attacked.

" The most satisfactory evidence that this spirillum is able to produce cholera in man is afforded by an accidental infection which occurred in Berlin, in the case of a young man who was one of the attendants at the Imperial Board of Health

* Arch. Hyg., lx, 16; also Chem. Abstracts, i., 1036.

† Metro. Water Board, 5th Research Report, June, 1910.

when cholera cultures were being made for the instruction of students." *

An entirely similar case came under the writer's observation, in Paris, while attending the course at the Pasteur Institute. One of the students, an Italian, was in the habit of constantly smoking cigarettes while at work. He became inoculated with Asiatic cholera through laying down his cigarette in contact with a cholera preparation. He took the typical disease and recovered. A friend of the author's reports a like instance of infection, observed by him while a student in Koch's laboratory.

Pettenkofer and Emmerich each swallowed pure cultures of the comma bacillus, with the result of producing only temporary diarrhœa, and they thereupon claimed that the germ is not to be considered as the cause of cholera. As opposed to this, Roux points out that the pure cultures referred to above may have been attenuated and very far from the point of virulence. Moreover, he shows that, even when truly virulent cultures are swallowed, the disease does not surely result.

Tersely stated, a disease follows when the active pathogenic organisms invade the body and find there not only suitable soil for their development but also the absence of antagonistic conditions which prevent their multiplication.

Dr. David Sommerville,† of Kings College, London, aptly says:

"The intensity of a disease is determined by the number and virulence of the particular germ on the one hand and the natural or acquired immunity offered by the body to this germ on the other.

"Many kinds of micro-organisms are permanent residents with us, ready to become dangerous at any time that the health falls below normal.

"Highly specialized cells of the human organism possess advantages but carry with them serious responsibilities. With high specialization has come increased delicacy.

* Sternberg's "Manual of Bacteriology," 1893.

† Section viii[a]. 8th Inter. Cong. Applied Chem.

"Pathogenic micro-organisms produce their deadly effects through the chemical substances they secrete. These toxins call out the production of neutralizing agents. Granted that the particular infection is not too intense and the body normally healthy for the most part, recovery ensues."

The President of the National Health Society of England some years ago said in an address: "We may lay aside all pedantry and mystery talk of epidemic constitution, pandemic waves, telluric influences, cholera blasts, cholera clouds, blue mists, and the like terms of art with which an amiable class of meteorologists has delighted to cloak their ignorance. Cholera is a filth disease carried by filthy people to filthy places. It only develops where it finds dirty places, and the dirty habit of drinking polluted water and living on a polluted soil. Cholera does not travel by air-waves or blasts. We drink cholera and we eat cholera, but we cannot catch cholera as we catch measles, scarlatina, or whooping-cough.

"Cholera is always carried. It never travels on its own account or by its own conveyance, and it is not half so bad a disease as it has been painted by a frightened public.

"It is stated on the authority of the head nurse that not a single case of cholera originated in the hospital of Hamburg during the recent epidemic in that city, though the sick were often placed two in the same bed and the dead in long rows. Amid the gloom and excitement scores of suspects were hurried off to the hospital who were afterwards found to be suffering from some other disease. Not one of these persons contracted the disease from the cholera patients with whom they were forced to associate. It would seem as if the safest place at the time of a great epidemic of cholera would be where there is the most sickness. All of these statements point to the fact that cholera is not infectious, and that the danger has been very greatly overestimated." *

"Pettenkoffer has given the key to the whole situation by saying that filth is like gunpowder, for which cholera is a spark. A community had better remove the gunpowder than

* British Med. J.

try to beat off the spark, for, in spite of their efforts, however frantic, this may at any time reach the powder, and if it does, is sure to blow them to pieces." (Sedgwick.)

The incubation period of cholera is commonly five days, about one-third of the time required to develop typhoid fever, but, although more rapid in its attack, the cholera germ is fortunately more easily destroyed; therefore the defensive measures taken against typhoid fever will abundantly serve to protect against the more serious disease.

Typhoid fever dwarfs all other water-borne diseases from the view-point of the sanitary engineer. The possibility of its outbreak is always with us; for it does not have to be imported, and consequently cannot be efficiently stopped from entry at our seaports as is the case with Asiatic cholera.

Its name "typhoid" is derived from the fact that it formerly was not differentiated from "typhus" fever, a disease also known as "jail" or "ship" fever and derived from the bite of infected lice.

Typhoid is slow in manifesting itself, the onset of the malady occurring about fourteen days after the specific organisms are swallowed. This period of two weeks is termed "the period of incubation."

A general condition of malaise gradually develops, accompanied by nose bleed, headache, rose spots on the abdomen, diarrhœa and with a rise of temperature which is quite characteristic, being higher in the evening and lower each morning. Serious cases pass into delirium and coma.

The intestinal discharges and the urine of patients ill with typhoid contain great numbers of the bacilli peculiar to the fever and it is the admission of such excretions to their food and drink that causes the spread of the disease among human beings.

Typical typhoid has followed the swallowing of a pure culture of the *B. typhosus* by a would-be suicide.*

Typhoid fever is unquestionably more fatal to the negro

* Arch. Gén. de Med., 1903: 2: 2197, also Jordan's Gen. Bact., 259.

than to the white race, if we judge by the death-rate alone. More black people die from the disease per hundred thousand living than is noted among the whites; but the thought presents itself, is this not really due to the larger case rate arising from the greater carelessness of the blacks as a class, and the consequent opportunity for contact transmission? No answer for this question is at hand, but the fact remains that, as Johnson has shown, the average typhoid deaths per 100,000 of each race living in twenty-four large American cities for 1910 to 1913 inclusive, stand: White 18.7 and colored 32.1.

Typhoid is by no means alone in its rating as essentially a " human " disease.

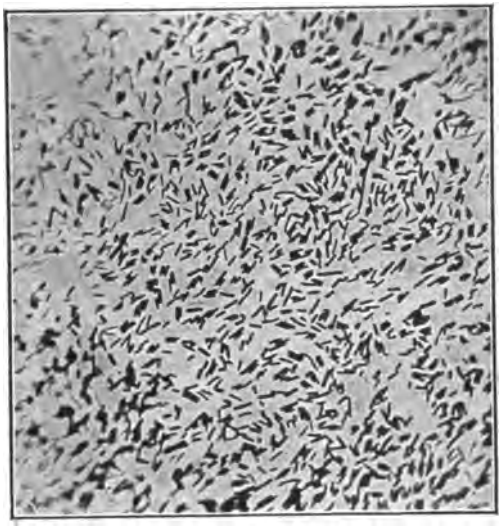
Scarlatina, syphilis and leprosy are among those belonging to that class; while, on the other hand, cattle plague, strangles, contagious pleuro-pneumonia and fowl cholera are instances of animal diseases innocuous to man.* Of course there are numerous diseases which attack both man and other animals equally well; for instance, the Bubonic plague, which, though a rat disease, is communicated to man by the bite of the rat-flea.

The typhoid bacillus is usually one to three microns long and from 0.5 to 0.8 micron broad. Its ends are rounded. Growth readily takes place at ordinary temperatures in culture media, and the colonies do not liquefy the gelatine. Spores are not produced. If added to milk it will develop abundantly, a property which has been productive of many serious outbreaks of the disease.

Blythe considers its probable normal existence that of a saprophyte—i.e., an organism subsisting on decaying organic material.†

There are others who believe, and it is a conceivable belief, that the progenitor of the typhoid bacillus is often a saprophyte, which takes on its pathogenic properties by cultivation through successive generations, under favorable conditions

* " Immunity in Infectious Diseases." Metchnikoff, page 41.
† Blythe, " Manual of Public Health."



BACILLUS TYPHOSUS, from twenty-four-hour culture on agar.
(From Hiss and Zinsser's "Bacteriology." Courtesy of D. Appleton & Co.)

BACILLUS TYPHOSUS, showing flagella. (After Fränkel and Pfeiffer.)
(From Hiss and Zinsser's "Bacteriology." Courtesy of D. Appleton & Co.)

as to light and temperature, and amid suitable surroundings. Many illustrations are available, in the world of larger vegetables, of great changes in structure and properties due to cultivation under an altered environment. Hansen, the eminent Danish investigator, dealing with unicellular yeasts, has shown that by subjecting these bodies to different environments for a number of generations he can from one original create many so-called species.* Isolated cases of typhoid may be thus accounted for where it would be difficult to suppose contagion from a previously existing case.

In a paper before the British Medical Association, H. R. Kenwood suggests the possibility of the typhoid bacillus being an evolution from the bacillus *coli communis*, an organism ever present in the intestines, and adds that greater changes may be artificially induced, both functional and morphological, in bacteria than are represented by the slight difference between the bacilli in question.

Klotz observes that: "Of the external influences which can be brought to bear on bacteria, alteration of the quantity or quality of the food supply plays the most important role, and leads to modification of their biological nature. If the colon bacillus be grown over an extended time in river water, its power to produce indol is diminished or entirely lost."

"Jenner found that he could revert *B. coli capsulatis* to an unencapsulated form by cultural methods. A remarkable difference was noted in the pathogenesis of these two varieties, for, as we know, *B. coli capsulatis* is very pathogenic for white mice, but becomes less fatal or even non-pathogenic on losing its capsule." †

Roux and Rodet hold very strongly that the bacillus *coli communis*, when grown under suitable conditions, may become pathogenic and produce typhoid.‡ Germano and Maurea arrive at similar conclusions after careful investigations.§

* See Bul. N. C. Board of Health, xvi. 100.
† Am. Pub. Health Asso., 1905, II, 35.
‡ Analyst, xxi. 118.
§ Central. für Bakteriologie, xv. 60.

A most disastrous outburst of typhoid occurred during June, 1902, at a famous school in Pennsylvania. No previous case of the fever had existed at the school and the water supply was secured from a deep rock drilled well. The sanitation of the entire establishment had been planned by an expert in such matters. Upon investigation it was found that a break in the sewer pipe had allowed sewage to seep down the outside of the well-casing to its bottom. The lack of a previous typhoid history is the interesting feature of this case, for the disease was apparently derived from "normal" sewage. We must nevertheless remember that the possibility of the presence of a typhoid "carrier" (see page 100) is to be reckoned with in all such cases.

Remlinger and Schneider published an article in the Journal of the Pasteur Institute, February, 1897, on "The Ubiquity of the Typhoid Bacillus," in which they conclude that "the *bacillus typhosus* is distributed in nature outside the human body," and they "incline to think that bacilli not pathogenic, and indifferent to the serum test, which are encountered in water and soil are only definitive types of the *bacillus typhosus;* at least the parentage is evident even if the identity is not absolute." *

It must not be assumed that those who favor the view of a saprophytic ancestry for the typhoid germ have the argument all their own way. Far from it. Doubtless the bulk of bacteriologists are ranged upon the other side; † but, while the specialists are searching for further light upon this question, the evolution, or saprophyte, theory is a good working formula for the sanitarian, and upon it he should for the present rest, remembering that typhoid fever and filth are very closely related.

"We have yet to learn that the excrement of healthy, much less diseased, mammals and birds is altogether harmless to man." ‡

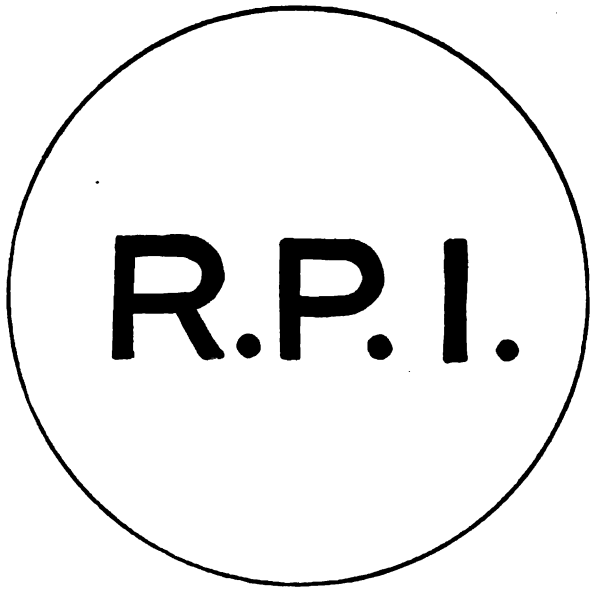
* In this connection see an article by F. C. Curtis on "Life-history of the Typhoid-fever Germ outside the Body," Albany Med. Annals, xviii. 167.

† E.g., Sedgwick in J. N. E. Water-Works Asso., xi. 255.

‡ Rideal, "Sewage," page 67.

The great influence of light upon the growth of the typhoid bacillus has been demonstrated by Janowski, who found that freshly inoculated gelatine, if kept in the dark, developed colonies in three days; if placed in diffused daylight, growth occurred in five days; but if the exposure were to direct sunlight for six hours, the gelatine became sterile.

This inability to survive long exposure to sunlight in presence of air is not peculiar to the typhoid bacillus. Fortunately



ILLUSTRATING STERILIZING ACTION OF SUNLIGHT.

for us, such sterilizing action is of wide application, and is one of nature's chief lines of defence against overwhelming bacterial invasion. A simple illustration, showing the inhibiting action of sunlight toward such common bacteria as liquefy culture-jelly, may be readily made as follows: Pour some melted jelly, previously inoculated with a drop of broken-down culture medium, into a Petri dish, upon the bottom of which have been pasted letters cut from black paper. When the jelly has set, expose the inverted dish for several hours in a cold place to the direct sunlight. After exposure, place the preparation

in the dark, at the usual culture temperature (20° C.). Liquefaction will be found to take place only in the portions shaded by the paper, and the letters will be found sharply countersunk in the jelly.

Burnett found that the water furnished to Colombo, in the island of Ceylon, although not of high quality from a chemical point of view, rarely contained more than two microbes per cubic centimetre. As the supply is from extensive, shallow surface-waters, the explanation is offered that nearly complete sterilization results from prolonged exposure to the direct rays of the tropical sun.*

All bacteria are not killed by direct sunlight, as, for instance, *B. photometricum.*†

It is generally observed that the number of bacteria in river-water is less in summer than in winter, but it must not be hastily concluded that this is due to the sterilizing action of light. As is shown upon another page, the summer feeders are commonly springs, while in winter much impure surface washing reaches the streams. Moreover, the action of light does not penetrate the water to any considerable depth.

The thermal death-point of the typhoid bacillus was found by Sternberg and Janowski to be 56° C. (132.8° F.), the time of exposure having been ten minutes.

That typhoid bacilli are not completely destroyed by exposure to low temperature, the epidemic at Plymouth, Pa., in 1885, clearly shows. As we have seen (page 32), the outbreak was traced to the dejecta of a single patient, which had been thrown upon the frozen ground and snow, during the early part of January, and which remained there until washed into the stream by the thaw occurring on March 26th. During this period the temperature had fallen to 22° F. below zero.

Very similar to the Plymouth outbreak is the one which occurred at Windsor, Vt., a town of some 2000 inhabitants,

* Chem. News, lxx. 285

† Wesbrook, J. Pathology and Bacteriology, London, Vol. iii., No. 4.

during the spring of 1894. For several weeks the typhoid germs remained in a frozen state, without having the potency of all of them destroyed.

As to the *longevity of the typhoid bacillus in water*, it is now generally admitted that such a medium is not favorable to its growth, and that although it may survive for varying periods, the length thereof depending upon local conditions, it rarely, if ever, increases in numbers, and it ultimately dies.

Frankland found that the great majority of typhoid bacilli died in raw river-water within a week's time, although a few remained alive over thirty days. He laid emphasis upon the fact that a factor determining "the longevity of pathogenic bacteria placed in water, or other unfavorable surroundings, is the absolute number in which they are present.

"Thus among 1000 bacteria from a given source there may be *some individuals* who will resist a particular adverse influence, while among 10 bacteria taken from the same source there may be *none* capable of resisting the adverse influence in question." *

Comparing "cultivated" typhoid bacilli, obtained from laboratory culture on agar, with "uncultivated" bacilli, obtained from centrifugalised urine secured from the same "carrier" that furnished the culture on agar, Houston established the remarkable fact that "uncultivated typhoid bacilli die much more speedily in raw-river water than their cultivated brethren." †

In eighteen experiments performed by him, in which he used inoculated river-water containing an average of 1,606,673 "cultivated" typhoid bacilli per cubic centimetre, he found that after laboratory storage in glass bottles for one week the average number present was only 531 per cubic centimetre, a reduction of 99.9 per cent. A few persisted beyond that time, but none lived nine weeks.

* J. Soc. Chem. Ind., 30, 327.

† 6th Research Report, Metro. Water Board, Nov., 1910.

In the same water inoculated with "uncultivated" bacilli direct from a "carrier" the count, at the end of one week, was reduced from 770,000 to 4 per cubic centimetre and at the end of two weeks all were dead.

This demonstration is very far-reaching, showing as it does that laboratory data touching the longevity of *B. typhosus* err on the side of safety; it being the "uncultivated" which we have to guard against in polluted water.

Whipple and Mayer have shown that *B. typhosus* lives much longer in water containing dissolved oxygen than in that from which such gas is absent; thus showing the lack of benefit to be derived from falls and rapids.*

Hoffmann found the germ to live longer in aquarium mud than in the water over the same.†

Whipple and Lochridge note that a forty minute exposure to .005 normal HCl or H_2SO_4 is fatal to *B. typhosus*, while *B. coli* requires four times that strength for like results. Hence mine water is unfavorable to the life of *B. typhosus*.

Elsdon and Evers find that in artificially carbonated waters there is a decided reduction of bacteria. Comparing the same water carbonated and uncarbonated there was a reduction in the former of 94 per cent in three days and 97.5 per cent in seven days, the counts being on gelatin kept three days at 21° C.‡

On the other hand, while Young and Sherwood consider carbon dioxide as somewhat toxic to *B. coli*, *B. typhosus* and other bacteria, they believe it is not so much so as to prevent disease transmission by means of carbonated beverages. Thus they have shown§ the following counts per cubic centimetre of *B. typhosus* and *B. coli* in the same liquid ("pop") carbonated and uncarbonated for the times specified. The carbonated liquids were filled at 10° C. and 18-pounds pressure.

* Am. Pub. Health Asso., 1905, ii., 76.
† U. S. Hyg. Lab. Bul., 35, 177.
‡ Analyst, 37, 395.
§ J. Indus. and Engr. Chem. III., 495.

	Carbonated		Uncarbonated	
	B. typhosus.	B. coli.	B. typhosus.	B. coli.
0 hours	200,000	950,000	200,000	950,000
4 hours	25,000	250,000	200,000	950,000
28 hours	9,000	20,000	50,000	lost
80 hours	1,200	1,300	6,000	100,000
244 hours	110	900	900	40,000

Pfuhl detected *B. typhosus* in artificially infected seltzer water after twenty-seven days.*

Mills reported the vital period of *B. typhosus* to be from seven to twenty-one days in Merrimack River water, and pointed out that this short period of existence presents the probable reason why the fever may be readily carried down a river from city to city, while a polluted stream may enter one end of a lake, whose waters are changed only after months, and a water-supply drawn from the opposite end may be much more free from specific pollution.†

One important point to be remembered is the antagonism between the disease germs and the common bacteria so largely found in surface-water. While such antagonism has been broadly noticed, Percy Frankland has placed the demonstration in the following form: He introduced typhoid bacilli into deep-well water which was almost wholly free from bacteria, into Thames water which contained a large number, and into Loch Katrine water, in which the number was intermediate between the two. He found that the typhoid bacilli died off more rapidly in Thames than in Loch Katrine water, while they persisted longest in the sparsely populated deep-well water. Thus the longevity of these pathogenic bacteria was inversely proportional to the bacterial population in the waters into which they were introduced.‡ Hence we see that a relatively pure stream, if a rapid one, might carry infection over long distances.

* U. S. Hyg. Lab. Bul., 35, 181.
† Am. Soc. C. E., xxx., 364.
‡ Water and Gas Review, Jan., 1897.

It should be noted here that the foes of the germs of disease are by no means confined to the other forms of bacterial life that may chance to be their neighbors. Organisms of larger growth, grouped under the general term "Plankton," serve as very energetic destroyers of the pathogenes and greatly aid in the sanitary improvement of water.

Inasmuch as experimental determinations such as the above, of the longevity of the typhoid bacillus have been commonly made in glass flasks under laboratory conditions, it is interesting to note that, for some reason, the data so secured are not strictly comparable with the facts as observed in nature. This is especially true if the glass vessels used be small ones. In commenting upon the divergent results secured by different observers, Jordan says: "Substantial accord has resulted on two points: first, that typhoid bacilli die out more rapidly in unsterilized water than in the same water sterilized by heat; second, that when typhoid bacilli are introduced into unsterilized water containing little organic matter, their longevity is more prolonged than in water charged with considerable organic matter." *

In order to secure conditions more nearly approaching those found in nature, Jordan, Russell and Zeit † abandoned the usual laboratory methods during their experimental work in connection with the Chicago Drainage Canal case and employed sacks of either celloidin or of vegetable parchment, which, after seeding with *B. typhosus*, were hung in the watercourse under investigation. The problem before them was, how long would the typhoid germs live in the water of the drainage canal and in that of the Illinois River? The sacks, having been filled with the canal or river water and seeded with typhoid bacilli, were then so hung as to prevent entrance of material floating upon the surface of the water. Under such circumstances dialysis would permit soluble products of bacterial origin to pass through the parchment in either direction, while organisms of any kind would

* J. Infectious Diseases, i., 641.

† *Ibid.*

be constrained to remain upon whichever side of the dividing membrane they originally found themselves.

Such conditions would serve to protect the imprisoned typhoid bacilli from an undue concentration of their own products of growth while exposing them to the inhibiting action, if any, of the toxins produced by the other organisms present in the outside water.

After extended experimentation along this line these investigators concluded that: "Under conditions that probably closely simulate those in nature, the vast majority of typhoid bacilli introduced into the several waters studied perished within three to four days. It is theoretically possible that specially resistant cells may occur which are able to withstand for a longer period the hostile influences evidently present in the water. Our experiments, however, show that if such resistant individuals exist they must be very few in number and constitute only a small fraction of the bacilli originally entering the water.

"It is not the intention of the writers to claim that the behavior of typhoid bacilli under the conditions herein described is representative of all conditions obtaining in all natural bodies of water."

The reliability of the foregoing experiments has been questioned by some observers,* but the subsequent and more extended investigations of Russell and Fuller † confirm their accuracy. Among the latter's conclusions we note: The longevity of *B. typhosus* in flowing water from Mendota Lake ranged from eight to ten days. When exposed to the action of sewage bacteria it was reduced to from three to five days.

When exposed to the diffusible products of sewage bacteria, but not to the direct action of the organisms themselves, the longevity of the pathogenic germs was increased.

"The question of longevity is more dependent upon the actual contact with sewage types than it is upon contact with by-products capable of diffusion through permeable membranes."

* Engineering Record, 52, 344.

† Am. Pub. Health Asso., 1905, ii., 40.

"The longevity of the typhoid bacillus in waters is materially affected by the germ content of its surroundings. In waters highly polluted with saprophytic bacteria, such as is the case in sewage, this disease organism is unable to survive for more than a few days (three to five in the experiments described), a period of time materially shorter than that which is noted in normally unpolluted waters."

In 1893 Sedgwick and Jackson arrived experimentally at the conclusion that typhoid germs would survive many days in sewage from which all other germs had been removed by filtration, thus showing that the saprophytic toxins were not fatal to their existence.*

Horricks reached a similar conclusion, but he found that the germ could not live fourteen days in raw, unfiltered sewage.†

Pickard claims that less than one per cent of the typhoid bacilli can maintain life in a septic tank for the above period.‡

Frith and Horricks found the bacillus alive in soil after seventy-four days; in dry sand after twenty-four days, and in peaty soil for a shorter period.§

Harris states that it can live long in dust and can produce true typhoid-pneumonia when inhaled.||

Dust infection is not unknown. Thus in Nottingham, a "dry-closet" town, there was a typhoid outbreak following the accumulation of large deposits of night-soil at the city refuse depots. Investigation left no doubt as to the source of the infection.¶

In sundry soils, kept moist, *B. typhosus* will live at least two months, without tending to grow or multiply. Such soil when converted into dust still contains live germs. The observations upon which this is based were not quantitative.**

From the results of recent investigators "it would appear

* Chicago Drainage Canal Case, viii., 7971.
† Rideal, "Sewage," page 66.
‡ *Ibid.*, page 63.
§ Thresh, "Exam. of Water," 139.
|| Sanitarian, 53, 311.
¶ J. Roy. San. Inst., xxvii., 533.
** Brit. Med. J., 1902, 936.

that all forms of moist human excrement, dirt, soil, sand or gravel favor the viability of the typhoid bacillus. Rullmann found that it lived for at least a year and a half in otherwise sterile earth and gravel, but in that time had died out in sand. The numbers were greatly reduced, however, greater in the earth than in the gravel.*

Wurtz found *B. typhosus* on the tips of growing vegetables, cress, lettuce and radishes, three weeks after sprinkling the soil with a watery suspension of the germ.†

Rullmann ‡ reports the recovery of *B. typhosus* from sterilized soil sixteen months after infection. From unsterilized soil it was recovered after one hundred days. The soil, however, did not contain many organisms of other types.

Tavel § points out, what has been noted elsewhere, that although *B. typhosus* does not live long in the water of streams and lakes yet it can exist for considerable periods in the mud upon their bottoms and sides, and he asks attention to the consequent danger possibly lurking in the "blind ends" of water pipes.

"The difference in resistance of the typhoid bacillus in soils and in liquids under apparently similar physical conditions may possibly be due to a greater amount of oxygen in the soils than in the liquids. This conception is of importance as it involves the question of the effect of the almost total lack of oxygen in the effluent of septic tanks upon the typhoid bacilli which are present in most raw sewages." ||

Dr. Martin, of England, finds that "if the bacillus be added to a cultivated soil the micro-organism cannot be obtained from such soil after twelve days or so." ¶ The shortness of this period is not in accord with the observations of sundry other writers, but it goes to support the general proposition that shallow rather than deep burial is the better way of dis-

* Pease, Albany Med. Annals.
† U. S. Hyg. Bul., 35, 184.
‡ Centralblatt für Bakteriologie, xxx., No. 8.
§ *Ibid.*, xxxiii., No. 3.
|| Pease, Albany Med. Anal.
¶ J. Fk. Inst., Oct., 1895, 302.

posing of excreta, for the reason that the upper level of the soil is the portion most densely inhabited by the organisms likely to inhibit the development of the typhoid germ. As compared with the millions of bacteria in the surface layer, the soil at the depth of a few feet may be considered as almost sterile.

At a mill at Canton, Mass., in June, 1888, out of 120 men some 50 were taken with typhoid. The families of these men were not affected. The drinking-water of the mill was from a well on the opposite side of a ledge and 54 feet distant from a privy-vault, which latter had received typhoid dejecta eight months previously. By experimenting with salt, direct connection by infiltration from vault was shown. Note the time-element in this case.*

Horrocks notes that "soil bacteria (the saprophytes of mould and earth) have a destructive effect upon *B. typhosus*."†

In his testimony in the Chicago Drainage Canal Case, Jordan compared *B. typhosus* and *B. coli* as follows with respect to their relative abilities to withstand certain adverse conditions:

"About 50 per cent of the *B. coli* and 75 per cent of the *B. typhosus* were destroyed by fifteen minutes freezing, after one hour 95 per cent of the *B. coli* and 98 per cent of the *B. typhosus* were killed, and at the end of twenty-four hours over 99 per cent of all the organisms had disappeared.

"Both species resisted temperature up to 45° C. for five minutes. And between 45° and 55° C. all but a few individuals of each were destroyed. These few individuals, however, resist temperature up to 85° C. at which temperature all organisms of both species are destroyed."

Comparison of the resisting powers of the two bacilli is important, as it enables us to safely assume the death of *B. typhosus* if *B. coli* should fail to survive. We may go a step further and say that, inasmuch as the spirillum of Asiatic cholera is more easily killed than the bacillus of typhoid fever, the *B. coli* will serve as a safety indicator for both.

* J. New Eng. Water-works Asso., v., 150.

† J. Roy. San. Inst., 32, 108.

As to the *diagnostic value to be attached to the presence of B. coli* in water it may be well to cite a report of a committee of the American Public Health Association presented at the Washington meeting.*

"To present a statement of the opinion of the committee individually and as a whole, as probably representing the generally accepted views of sanitary bacteriologists as to the significance of *B. coli* in water, the following questions were sent to each member. The answers were practically as given below:

"1. In view of the fact that numerous investigators have found *B. coli* in nature where it could not be directly traced to sewage or fecal pollution, do you believe that the colon test of water is as safe an index of pollution as it was formerly regarded to be?

"Yes.

"2. Are you of the opinion that the number of colon bacilli rather than their presence should be used as a criterion of recent sewage pollution?

"Yes.

"3. To pronounce a water sewage polluted, would you require as evidence that *B. coli* were present in a majority of one cubic centimetre samples?

"Yes, in general."

In this connection Houston says: "The death of *B. coli* is as sure and safe an indication of the death of the microbes of water-borne disease as, to take a homely illustration, the death of coarse fish in a water would lead the fisherman to assume the coincident destruction of the less hardy forms of fish life, e.g., trout." †

While noting the foregoing it must not be forgotten that the presence of a few *B. coli* may be due to very ordinary causes; thus some of them found in a reservoir may have come from the excrement of birds or through infection of the water by dust from a nearby highway.

Mr. N. S. Hill advises the writer that sparrows roosting on

* J. Am. Med. Asso., 1903, page 1292.

† Fourth Report Metro. Water Board, June, 1910.

the open well outlets caused the appearance of *B. coli* in a deep-well supply of which he had charge.

The rating of *typhoid fever as a "country disease"* has been frequently proposed.

In an address by Dr. J. S. Fulton of the State Board of Health of Maryland in 1905,* the speaker quoted data showing that the several states could be classified on a decending scale "of population density, showing typhoid mortality increasing as rural conditions more and more prevail." Thus the percentages of rural populations and the typhoid death-rates then were:

95 per cent population rural	.....	67 per 100,000 died	
87 " " "	.....	62 " "	
75 " " "	.....	46 " "	
67 " " "	.....	38 " "	
49 " " "	.....	42 " "	
30 " " "	.....	25 " "	

For Vermont, which is essentially a rural state, only 13 per cent of its population being collected in cities, Stone and Moat † report that the rate for the urban population is 27.8 per 100,000 while the rural rate reaches 31.7.

The census gives for the "Registration States" the following average typhoid death-rates per 100,000 inhabitants for the years 1910–1913 inclusive:

Urban	18.2
Rural	20.5

For the state of New York the typhoid rate for 1912 was:

For the largest six New York cities	10.1
For the "rest of district"	12.0

The expression "rest of district" is used to cover that portion of the sanitary district yet remaining after the cities,

* N. Y. Bd. Health, 1905.

† Ground Waters of Vermont, Am. Pub. Health Asso.

towns, and villages have been accounted for. It embraces the most rural portion of the community.

More recently this difference has grown smaller and in 1915 the former relation was reversed for the State of New York, the figures being:

Typhoid rate for the cities of the state..... 7.95 per 100,000
Typhoid rate for the entire state..... 7.7 "

The difference observed in many parts of the country between the city and country rates must be largely due to the greater care exercised in the selection of a water-supply for a city as compared with that so frequently displayed in the sinking of a country well. It would seem that a due saving of the steps of the housewife is what many a well-digger thinks about when selecting a site for his well, and he digs it in the most convenient position, without regard to local surroundings.

The maintenance of the water-supply in a pure state is not of itself enough to eliminate typhoid fever, as the disease has a number of other channels through which it can be transmitted.

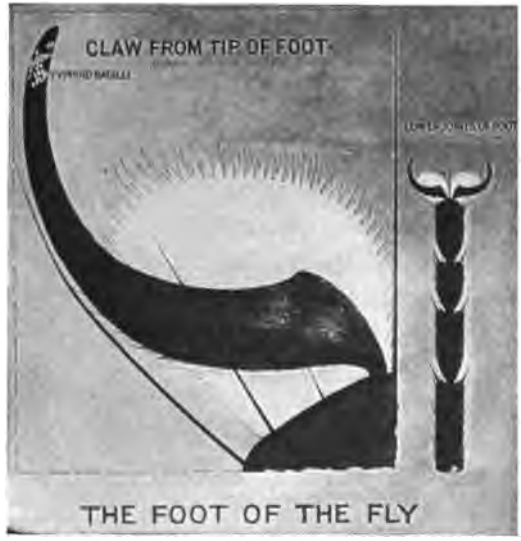
Infected milk is a common source of typhoid, the infection being caused by washing milk cans in infected water. Given a polluted well upon a dairy farm there may be greater danger in using its water for washing milk containers than in using the water itself for drinking, because milk is a medium in which typhoid germs will develop and multiply while water is not.

The "spot-map" of a "milk epidemic" is characterized by the spots being likely to appear along a particular milk-route; moreover, young children figure largely in the list of cases, and the outbreak is likely to be of an "explosive" type.

Typhoid distribution by flies has often been the real origin of epidemics of the fever when the water supply has been blamed as the cause.

At 70° F., or over, the life cycle of the ordinary house fly can be completed in ten days. Each female may lay four or five batches of eggs containing somewhat more than 100 eggs in each. Howard estimates that the immediate descendants of

a single pair of flies might number twelve millions and weigh 800 pounds. Flies take only liquid food. When feeding on dry material they regurgitate liquid material from their "crop" whereby solution of the food is secured and then the "enriched mixture" is sucked in. The fly's feet "have each a two-lobed pad, covered with a dense growth of very minute tubular hairs, from which a sticky secretion can be exuded; it is by means of this apparatus that flies are enabled to walk on smooth surfaces in any position."



(After Howard.)

Dr. Graham-Smith * sets forth some of the dangers attending the habits of the fly and shows that "infected flies not only carry bacteria on their bodies and limbs, thereby contaminating substances over which they walk, but distribute bacteria which they have ingested, by means of vomit and fecal deposits." He shows that, while non-spore-bearing bacteria survive at the most only twenty-four hours on the limbs, flies nevertheless infect substances over which they walk with such organisms for several days by means of a fluid which

* "Flies in Relation to Disease," 1913.

they regurgitate from their crops. He also shows that "the majority of the non-spore-bearing bacilli pass through the intestine and are in living conditions in the fecal deposits."

"Flies carry in and on their bodies very large numbers of bacteria, many of which are fecal types, and these are more numerous in flies caught in congested or dirty areas. Pathogenic bacteria or allied types have been isolated from wild city flies."

Wherever human excreta are exposed to the reach of flies as in unscreened privies, there is always danger of such material being transported to the neighboring kitchen, with consequent infection of food. This form of typhoid distribution was the source of the serious outbreak of the fever among the American troops during the Spanish War.

Dr. L. O. Howard calls attention to the fact that, "during that war, in the temporary camps sufficient attention was not paid to protecting the latrines from the visit of flies, and in such camps typhoid abounded, while in camps adopting such precautions, especially such permanent camps as the Presidio, typhoid was almost unknown." *

In a typhoid epidemic reported by Dr. Hamilton: "The streets in which the sanitary arrangements are worst had the largest number of cases, irrespective of the poverty of the inhabitants.

"Flies caught in two undrained privies, on the fences of two yards, on the walls of two houses, and in the room of a typhoid patient were used to inoculate eighteen tubes, and from five of these tubes the typhoid bacillus was isolated." †

In cities and sewered towns where the yard privy is less commonly found, fly infection plays a less conspicuous part; nevertheless, lack of house plumbing is far from rare, even in large places, and "fly typhoid" epidemics are still in evidence. The "spot map" of such an epidemic is characterized by irregularity in the location of cases. The "spots" are found

* Pop. Sci. Monthly, Jan., 1901.
† J. Am. Med. Asso., Feb. 28, 1903.

in the poorer parts of the town, where absence of plumbing and the carelessness and ignorance likely to exist in such localities allow of the exposure of both excreta and food to fly invasion.

Typhoid from infected shell-fish follows from the fattening or growing of them in polluted waters. Unfortunately some of the localities whence wholesome oysters have been taken in the past are now exposed to serious sewage inflow with the result that the shellfish taken from such beds carry with them a menace to health. Still more objectionable is the practice of fattening oysters for the market by transplanting them to the mouth of some stream if such stream be a polluted one, as sometimes happens.

It is a fortunate fact that oysters close their shells for the winter, hibernate in short, and consequently are relatively safe during the cold months.

The remedy against the danger of shellfish infection is a legal one, namely, the closing of polluted waters to oyster culture and the proper protection of established oyster-beds from sewage inflow.

The securing of protection against the entrance of disease through any of the channels named should, however, be supplemented by supervision of general hygienic conditions as well, otherwise the resisting powers of the human organism may be lowered and left unable to successfully oppose the invading germs, should they come from some unexpected source.

The experimental results of Charrin, Roger, Pasteur and others,* bear directly upon the relation of insanitary surroundings to the development of typhoid, and also upon the fact that the *effect of physical exhaustion*, whether due to cold, fatigue, hunger or other cause, is to predispose to the contraction of disease.

The following is quoted from the Bulletin of the Indiana State Board of Health: "On one of the farms the well became infected, and of twelve men who drank water from it during

* See Sternberg's Bacteriology; also J. San. Inst., xvi., 487.

one day, eight acquired typhoid fever within two weeks. It is interesting to note the fact that the eight men who were attacked were very tired and quite worn out when they drank the infected water."

It is to be presumed that the water-closet system is the one which most quickly and efficiently carries away dejecta from the premises, and we should expect a corresponding benefit to be reflected by the typhoid statistics.

The following record for the city of London * covering houses possessing three forms of sewage disposal speaks for itself:

Houses with privy system, 1 case of typhoid for every 37 houses.

Houses with pail system, 1 case of typhoid for every 120 houses.

Houses with water-closet system, 1 case of typhoid for every 558 houses.

Of course some allowance for "secondary" typhoid, due to unsanitary habits, must be applied to the above data.

Considerable discussion, pro and con, has been raised with reference to the *influence of "sewer-air"* upon the spread of typhoid fever.

W. H. Horrocks † summarizes his experimental investigation as follows:

"Specific bacteria present in sewage may be ejected into the air of ventilation pipes, inspection chambers, drains and sewers by (*a*) the bursting of bubbles at the surface of the sewers, (*b*) the separation of dried particles from the walls of pipes, chambers and sewers, and probably by (*c*) the ejection of minute droplets from flowing sewage."

Professor Winslow strongly opposes this view of Horrocks and advances experimental evidence in support of his objection; but there is another point from which the question may be viewed. Even though we grant the absence of pathogenic

* "The Purification of Sewage," Barwise.

† J. Roy. San. Inst., May, 1907.

germs from sewer air, yet surroundings which offend the senses indirectly lead towards disease by a lowering of resisting power, just as *vice versa* the placing of a patient amid pleasant surroundings aids in the accomplishment of a cure.

There is a direct relation between some forms of filth and disease, though such relation may not be always manifested: and there is an indirect relation between disease and all forms of filth that are appreciable by the senses, and this latter indirect relation is the more common of the two.

Consideration must be given to the feelings and views of those whose beliefs are centered upon a close relation between any form of sewage pollution and disease, even though the sanitarian may not fully endorse the opinions of such persons from a purely scientific standpoint.

"Faith cures" are recognized as really curative in some disorders, and likewise a strong belief in the bad results likely to arise from certain existing surroundings, held to be objectionable, must be allowed to have depressing effects upon the normal resistance to disease invasion.

With the advance in the inspection and care of water supplies it must of necessity follow that they will become less and less a causative factor of disease, and the typhoid of the future will, relatively, be more frequently traced to other sources.

It is wise to call attention to the prevalence of mild and unrecognized cases of typhoid fever, and to the greater danger arising from them, and it might be added that such cases are dangerous to the patient as well as to the neighbors, by reason of the lack of care given them and the consequent exposure to relapse.

As to the likelihood of the disease spreading throughout a household by "counter infection," that will largely depend upon the class of people among whom the fever primarily appears. With filthy people the danger is material, but among those of cleanly habits, who are alive to the necessity of following sanitary instruction, there is small reason to fear an extension of the disease.

"*Secondary*" and "*residual typhoid*" are terms intended to cover those cases arising from causes other than the water supply; the first due to the filthy habits of people who may handle food, and the second to other causes not specifically classified. At the present moment it seems that, for American communities, an average yearly mortality of about fifteen per hundred thousand inhabitants must be counted as due to these two causes.

The number is large and it is hoped that it may be lessened by the extension of a better popular knowledge of the origin of typhoid and of the methods of guarding against its occurrence.

Typhoid in general, and therefore residual typhoid as well, has been lessened for the State of New York, as is shown by the following record (compiled by Theodore Horton):

ANNUAL TYPHOID DEATH RATES PER 100,000 POPULATION (STATE OF NEW YORK)

1895.....25.4	1900.....26.7	1905.....19.7	1910.....15.0
1896.....22.6	1901.....23.4	1906.....19.0	1911.....14.0
1897.....19.4	1902.....17.4	1907.....19.8	1912.....11.8
1898.....25.6	1903.....21.5	1908.....16.0	1913.....10.5
1899.....22.4	1904.....20.9	1909.....15.1	1914..... 8.8
			1915..... 7.7

A list of typhoid rates for sundry large cities of the world will be found on pages 39 and 40.

Dr. Rideal of London has suggested that fittings be installed in each house, such as Pasteur filters, heat sterilizers and the like, which same, being placed under municipal control, sterility of the public water supply used for drinking could be insured,* with consequent reduction of the typhoid rate.

Such a procedure would not be practicable, for the reason that the ignorant portion of the community must be furnished with a water that is "safe from the faucet."

After all sources of possible danger have been examined, it must be admitted that outlying isolated cases of typhoid

* J. Roy. San. Inst., xxvi., 679.

fever are often difficult to explain; but it should not be forgotten that the disease does not manifest itself until a considerable time after infection, the incubation period being usually about fourteen days, and therefore the possibility of its having been imported should be always borne in mind.

"After the reception of the infection, there is, in all communicable diseases, an interval during which the patient remains in apparent health, or perceives at the most some languor. This period lasts from one to five days in the case of cholera. For typhoid fever its duration varies from nine days to three weeks. The latter disease begins so gradually that the patient generally does not come under the observation of a physician until he has had the fever for several days. If water infected by typhoid-fever dejecta were to be drunk by a considerable number of persons August first, the first case would appear about the ninth or tenth, and fresh cases would continue to appear until the twenty-third. There would be more on the fourteenth or fifteenth than at any other time. The deaths would nearly all occur the next month—September. These laws of development are of great aid in discovering the cause of brief epidemics, by indicating the period in which it must have been common to all the persons attacked." (E. J. Matson.)

An argument always advanced against the proposition that a typhoid epidemic in a town is to be accounted for by the use of a contaminated water-supply is that only a few of the inhabitants are attacked, while all use the water. Why should the majority escape? For full discussion of the wide subject of "immunity," thus introduced, the reader must be referred to the extensive monographs written thereon; but let it be here said that immunity depends at least in part upon an inherited or acquired tolerance to the toxic products of pathogenic bacteria.

This question of "tolerance" is of wide application and affects many forms of life. Thus, according to Metchnikoff: *

"Whilst the lower organisms are refractory to bacterial

* "Immunity in Infectious Diseases," pages 21 and 24.

toxins which in quite small doses are capable of killing man and the higher animals, many micro-organisms manifest a special sensitiveness to certain fluids of animal origin. The blood of the rat contains an organic base capable of killing and dissolving a considerable number of anthrax bacilli." Yet it is possible "by successive cultures to accustom the anthrax bacillus to an existence in the pure serum of the rat. The bacillus protects itself against the toxic action of the serum by surrounding itself with a thick sheath composed of a kind of mucus which fixes the toxin of the rat's blood and renders it harmless.

"Stentors kept for two days in a weak solution of corrosive sublimate (.00005 per cent) acquire a tolerance to a dose of this poison four times as great as the lethal dose for individuals previously kept in pure water."

It is very possible that those people who use a polluted river water, and are therefore daily exposed to invasion by greatly attenuated typhoid organisms, may gradually acquire an immunity against even virulent bacilli, which protection would not be possessed by the visiting stranger.

According to the theory of phagocytosis advanced by Metchnikoff, invading pathogenic organisms are seized upon by the guarding leucocytes of the blood, and destroyed by a process of assimilation, provided "the captors are not paralyzed by some potent poison evolved by their prisoners, or overwhelmed by their superior vigor and rapid multiplication."

"Micro-organisms, after their entrance into a refractory animal, are not eliminated by any of the excretory channels which serve for the elimination of many of the soluble poisons." *

Invasion of a susceptible animal by a single disease-germ may prove fatal, as has been shown by Cheyne, who experimented upon guinea-pigs with anthrax; † but if any considerable degree of vital resistance be present, the "bacterial dose"

* "Immunity in Infectious Disease," page 46.

† See also "Principles of Bacteriology," by Hueppe, Trans. by Jordan, page 152.

may have to be very greatly enlarged to produce observable effects. Thus the above investigator found that "for rabbits the fatal does of the microbe of fowl cholera is 300,000 or more, that from 10,000 to 300,000 cause a local abscess, and that less than 10,000 produce no appreciable effect." He found 225,000,000 of the *Proteus vulgaris* fatal to rabbits, but that less than 9,000,000 gave an entirely negative result.

Another interesting point that arises in this connection is the wide difference between the intensity of the attacks induced by a "virulent" and an "attenuated virus." It is well known that, if the conditions attending the cultivation of a pathogenic microbe be unfavorable to its ready growth, if they be just short of the death-point, if the germ be obliged to struggle for existence through successive generations, the result is an organism of less vigorous constitution, and one capable of producing only a fraction of the amount or intensity of "toxin" elaborated by its sturdy progenitor.

Inoculation with such "attenuated virus" might be fatal to the very susceptible, but a larger number of the resistant portion of the community would escape, and the great majority of all cases occurring would be designated as "mild."

Typhoid epidemics following the use of polluted river water are commonly mild in character, while isolated country cases of the disease are often severe. Such has been the writer's experience, and a reasonable explanation would seem to be that while the adverse conditions of river carriage supply abundant opportunity for the pathogenic germs to either die, or to at least lose a portion of their virulence, the conditions governing the supply of water from an infected well usually admit of a shorter period of time to elapse between the entrance of polluting material and the drinking of the water. In other words, the struggle for existence during stream transmission will cause a decrease in the "poisoning power" of the typhoid germ, which decrease will vary directly with lapse of time, and will consequently be a function of both distance and velocity of flow. Bacilli, therefore, which started on their journey in vigorous condition might be considered as arriving at the point

of invasion in a state so enfeebled as to be incapable of producing a "normal" type of the disease.

Such a proposition was advanced by the writer some years ago in a case involving the question of water-borne typhoid, and the following data are offered in support of the argument.

There arose an opportunity to study an outbreak of typhoid fever occurring among people who used waters of widely different characters. The public supply of the city was from a stream which received the sewage of a town a few miles away, and many cases of typhoid occurred among those who exclusively used such water. Throughout the city there were numerous grossly polluted domestic wells, and fever cases were plentiful among families using water from no other source. As was to have been expected, a still larger number of cases of the disease were found where the water drunk was from both the wells and the river. A careful house-to-house visitation elicited the following data. The division of the cases into "light" and "severe" rests upon the statements of the attending physicians.

Water Used.	Number of Cases.	Light Cases.	Severe Cases.	Ratio of Severe Cases to Total Cases, Per Cent.
Stream.....	61	44	17	27.80
Well.....	46	20	26	56.50
Mixed.....	132	72	60	45.45

Data such as the above are very difficult to secure, and we are usually forced to rest satisfied with mortality returns alone, but even from such unsatisfactory material our proposition receives no small measure of support.

In a report prepared for the Parliamentary Bills Committee of the British Medical Association, Hart gives sundry figures for a number of British epidemics of typhoid fever. It is possible to pick out from his collection of facts 108 instances where the disease could be traced to contaminated wells upon the one hand, or to polluted reservoirs or streams upon the other. The table here following gives the average death-rates for the two classes of epidemics, and there are added the figures

for milk epidemics also, although such are foreign to the present discussion.

	Average Death-rate, Per Cent.
75 epidemics due to well waters	11.83
33 epidemics due to stream and reservoir waters	9.85
20 epidemics due to milk	12.79

In speaking with the writer upon this general subject, a Philadelphia physician of large practice said that his typhoid death-rate in private practice was about 5 per cent, but that upon one occasion it was much higher. He was called to attend an outbreak of the fever occurring among a considerable number of Russian sailors, who had been sent to Philadelphia to man a battleship then building at Cramp's shipyard. These men drank water from a well which was afterwards proved to have been grossly polluted. The typhoid death-rate resulting among them was about 20 per cent.

Such figures as have been given certainly tend to show that greater or less concentration of polluting material and longer or shorter exposure of the typhoid germ to unfavorable surroundings must be held to account in part at least for the variability observed in the intensity of the disease.

It is an odd fact that when typhoid is not very prevalent in a city the death-rate is often high—most of the patients die; but when the fever is really widespread and there is an epidemic, most of those attacked get well. That merely shows, of course, that when there is but little typhoid the cases are not reported. Physicians will report cases during an epidemic, but they will often not report them during a non-epidemic period unless they be fatal.

Thus for the city of Columbus, Ohio:

	Cases Reported.	Deaths.	Fatality, %
January, 1904	725	35	4.83
February, 1904	798	94	11.78
March, 1904	83	33	39.76
April, 1904	28	9	31.14

Typhoid fever is essentially an autumn disease in this latitude. Thus we find the following returns of the N. Y. State Department of Health for the year 1912:

The number of deaths from typhoid fever, as reported by months, was as follows:

	Urban.	Rural.		Urban.	Rural.
January	86	21	July	68	11
February	59	11	August	105	16
March	56	12	September	115	22
April	57	11	October	113	30
May	66	18	November	77	12
June	56	11	December	61	18

United States census records show that during the year of 1910 there were 12,673 typhoid deaths in the "Registration Area." These deaths were distributed as follows over the twelve months of the year:

January	728	July	832
February	673	August	1,460
March	788	September	1,917
April	652	October	1,858
May	578	November	1,530
June	626	December	1,041
			12,673

Data such as the foregoing, and others that might be given, indicate the autumn to be normally the "typhoid season."

Temperature conditions have much to do with the seasonal distribution of typhoid fever.

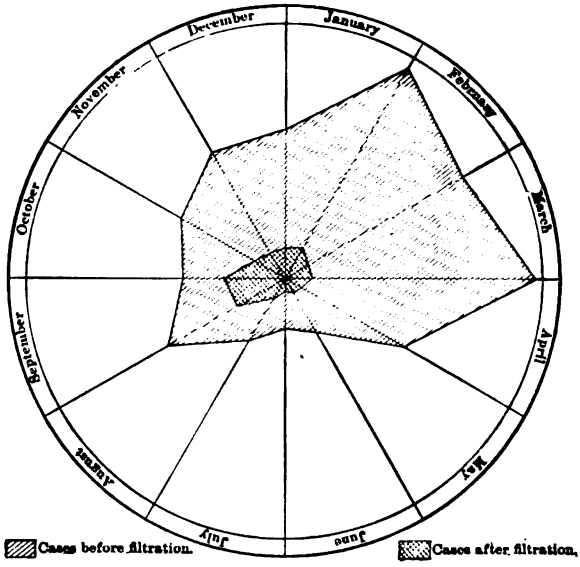
If we remember that summer is the time when flies are most numerous, and also bear in mind that each developed typhoid case is but an additional centre from which yet another may arise, we can see how likely it would be that the summer inoculations of the fever would swell the autumn death reports.

The observation has been made that cities which take their water from polluted rivers are prone to be exceptions to the

autumnal typhoid rule and exhibit their outbreaks of the disease in winter or spring.

The illustration given herewith shows the amount and monthly distribution of typhoid fever at Albany, N. Y., during periods before and after the establishment of the city filter plant.

It will be observed that the improvement in the quality of the public water has done more than simply decrease the



MONTHLY DISTRIBUTION OF TYPHOID FEVER AT ALBANY N. Y.
(Courtesy of F. R. Lanagan, City Engineer)

amount of typhoid; it has altered the time of its maximum intensity as well. What typhoid yet remains in Albany is now an autumn disease and has lost the winter high-point which it formerly possessed.

The chart indicates how the " water-borne " portion of the annual typhoid enveloped the " residual " and by its greater volume obscured the latter and changed the average date of incidence.

The installation of filters at Providence, R. I., produced

an entirely similar result upon the typhoid statistics in that city. The improvement of the water resulted in lowering the typhoid rate and in changing its date of maximum occurrence from December to October.

Ruediger * shows that both "*B. coli* and *B. typhosus* disappear much more rapidly from polluted river water during the summer months than when the river is covered with ice and snow."

Houston in his seventh research report to the London Water Board gives in great detail data showing that "temperature is an important factor as regards the vitality of the typhoid bacillus in river water, and the lower the temperature the longer does the bacillus survive." He found that in raw Thames water, which contained 103,328 typhoid bacilli per cubic centimetre, the average reduction in number of germs per cubic centimetre was as follows for a storage of one week at the temperatures given:

32° F.	47,766	remaining,	or	46.22	per cent
41° F.	14,894	"	"	14.4	"
50° F.	69	"	"	.06	"
64.4° F.	39	"	"	.03	"
80.6° F.	19	"	"	.01	"

Thus we are to expect the *B. typhosus* to live its life more rapidly and vigorously during warm weather and to quickly pass to its death with the assistance of other forms of life then existing in plenty; while under the influence of cold it would appear to assume a sort of hibernating state and thereby greatly prolong its existence.

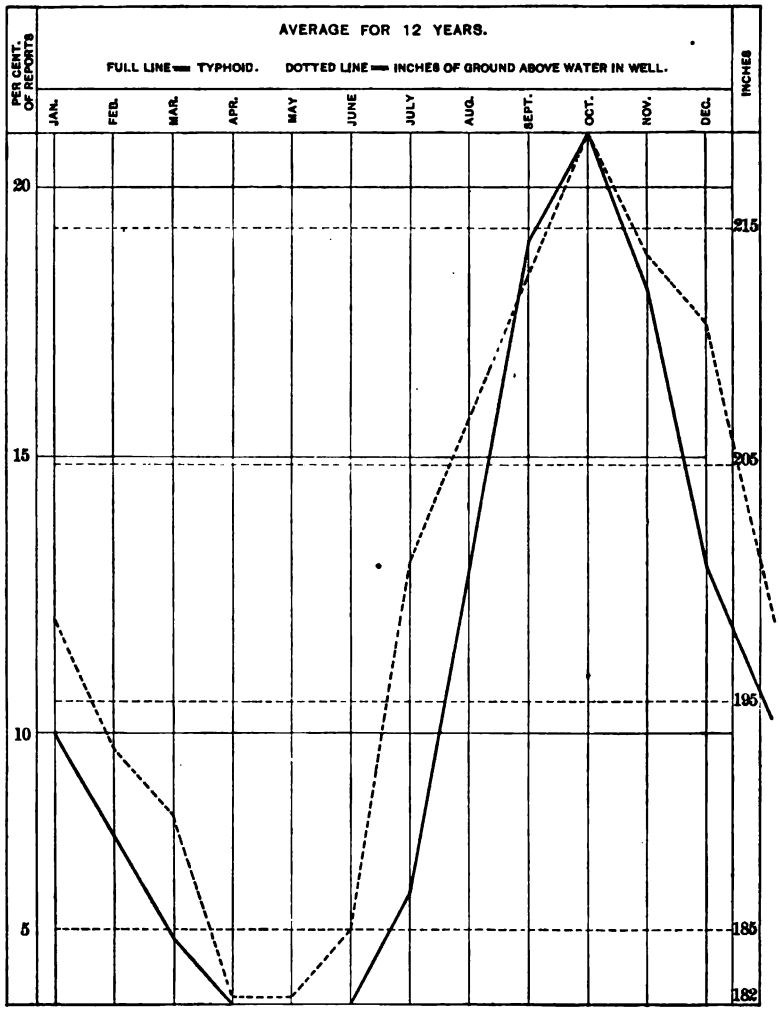
The above facts serve to explain why the maxima of typhoid outbreaks, caused by polluted river waters, are pushed forward into the colder months of the winter and early spring.

Typhoid fever and height of ground water was a relation commented upon by Dr. Michel, of Chaumont, France.† In

* J. Am. Pub. Health Asso., June, 1911.

† "Influence de l'eau potable sur la santé publique." Paris, 1889.

1855 he observed that typhoid, which was epidemic in the above place, varied in number of cases and in intensity inversely as the quantity of water in the public wells.



COINCIDENCE OF PREVALENCE OF TYPHOID FEVER AND LOWNESS OF WATER IN WELLS. (STATE OF MICHIGAN.)

Latham, in speaking upon this point, says:

"No great variation in the vertical rise and fall of subsoil

water is the healthier condition. Dry summers invariably mark unhealthy years. Typhoid fever occurs after the autumn rains.

"All the great epidemics of typhoid have occurred in years when the ground-water was especially low, and after a slight rise in the same."

He especially refers to the year 1741, "which was one of the driest periods known, and the most unhealthy period in many places that has ever been recorded." *

A reasonable view of the situation is that, as the water-surface lowers in a well, the base of the cone of drainage, whose apex is at the water surface, is extended, and consequently more widely situated points of pollution are embraced within its influence.

Perhaps the most exhaustive examination of the relation of the height of ground-water to the prevalence of typhoid fever that has been made in America is to be found in the work of the State Board of Health of Michigan.

Observations have been made by that board during a period of many years, and the height of the water in a representative well near the centre of the State has been regularly measured. The results, graphically shown herewith (see page 92), indicate in a marked manner that increase of typhoid and lowness of water in wells move in practically the same curve of variation.

Whether the exhaustive study of facts does or does not support the view that the relation of typhoid fever and rainfall, so far as ground-water is concerned, deals with the question of low ground-water rather than with fluctuations in its vertical height, it admits of ready illustration that marked relationship certainly exists between this disease and the sudden influx of storm-waters, flooding the polluted foreshores of smaller rivers. We have seen such a case in the epidemic of typhoid in the valley of the Tees, page 26.

As cities increase in size there are introduced into the total death-rate disturbing factors that must be considered in com-

* J. Roy. San. Inst., 31, 457.

prehensive study. Thus the influence of simple crowding is well illustrated by the following statistics for various London districts: *

	Mean Death-rate, 1885–91.
Districts with a density of under 40 persons per acre....	15.27
" " from 40 to 80.....	19.04
" " from 80 to 120.....	19.24
" " from 120 to 160.....	22.60
" " over 160.....	23.88
County of London, with a density of over 57.....	19.90

In view of the intensely practical spirit of the age, let us consider the question,

Does pure water pay?

To abandon an existing water-supply system, or to purity the polluted water that it furnishes, always involves the outlay of much money, and the city taxpayer has the right to inquire whether or not the benefit derived is a fair equivalent for the cash expended.

Typhoid fever is doubtless, to a large extent, a preventable disease, but the means of prevention, in the shape of great public works, are expensive, and the question is very properly asked, Do these works pay? Can we afford to save the typhoid victims?

Before answering let us note that the age at which typhoid fever most commonly occurs, as shown by the above chart, is the very prime of life.

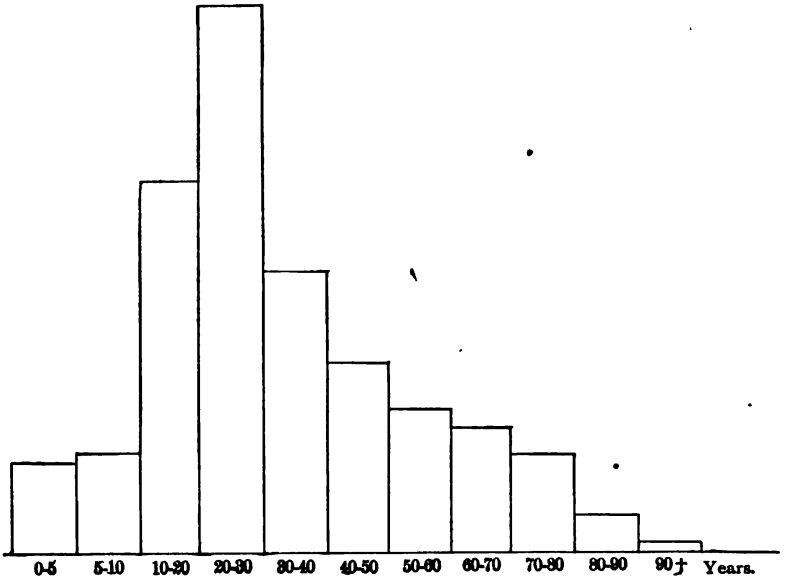
According to Rochard, the economic value of an individual "is what he has cost his family, the community, or the State for his living, development, and education. It is the loan which the individual has made from the social capital in order to reach the age when he can restore it by his labor."

The statement of this value, in form of money, is a difficult matter, which has been variously settled by sundry investi-

* Engineering News, Dec. 28, 1893.

gators. Chadwick considers an English laborer equivalent to a permanent deposit of £200 (say $980). Farr gives £159 (say $780) as the average value of each human life in England. A French soldier is rated as worth 6000 francs (say $1200).

In view of the fact that typhoid fever selects by far the greatest number of its victims from among those in the very



SHOWING TYPHOID DEATH-RATE AT DIFFERENT AGES, FOR THE STATE OF CONNECTICUT.*

prime of life, to the relative exclusion of the very young and the very old, it will be reasonable to follow the figure fixed upon by E. F. Smith, and place the loss caused the community by a death from typhoid at $2000. This will be noticed to be less than half the figure so frequently referred to in the courts of this State as the value of a human life.

For the sake of illustration, let us consider the tax formerly

* Rep. Conn. Board of Health, 1895, p. 165; see also a similar chart in the Report for 1903, xxi.

levied annually by typhoid fever upon the city of Albany, N. Y.*

The population of Albany is about one hundred thousand, and from statistics given in the reports of the State Board of Health the deaths due to typhoid fever in Albany formerly averaged seventy-five for the year.

Rating the money value of each life at the figure given above, this death-rate would mean an annual pecuniary loss to the city of $150,000.

Funeral expenses are variously extimated at from $20 to $30. Should we accept the intermediate value of $25, this item would cause $1875 to be added to the above sum, thus raising the total direct loss through death to $151,875.

But typhoid fever does not always kill. Its mortality rate is commonly quoted at about 10 per cent. For the present purpose, should we assume nine recoveries for each death from the disease, and place 43 days as the period of convalescence (the average of 500 cases at the Pennsylvania Hospital), we should have a term of 29,025 days as representing the time lost, per year, by the 675 persons who have the fever and recover. Thus an annual loss of over seventy-nine years had to be borne by the city's capital of productive labor.

This great amount of enforced idleness, when translated into money value, should very properly be added to the death-loss above estimated.

Fixing the rate of wages at $1 per individual per day—a very low figure, considering that the bulk of typhoid patients are in the very prime of life—there formerly was a loss of $43 of wages for each recovery, or a total yearly loss for the city from this item of $29,025. The cost of nursing and doctors' bills equals at least $25 per case, which is a very low estimate, thus adding the further amount of $16,875 to the gross sum. Expressed in tabular form, this yearly tax formerly imposed by typhoid fever upon the city of Albany is given below, and, upon a most conservative estimate, it was practically $200,000,

* Albany now possesses a modern and efficient filter-plant. See page 144. The typhoid rate for 1915 was 12 per 100,000.

or $2 a year for each man, woman, and child in the city or a yearly tax of $10 for every family of five persons.

75 deaths at $2000 each	$150,000
75 funerals at $25 each	1,875
Wages of 675 convalescents during 43 days at $1 per day	29,025
Nursing and doctors' bills for 675 convalescents at $25 each case	16,875
Total tax formerly levied annually by typhoid fever upon the city of Albany	$197,775

Dr. V. C. Vaughn estimates the annual number of typhoid cases in the United States as half a million, with 50,000 deaths, and he places the annual cash loss resulting from the same at $90,000,000.

It can readily be seen that public works which eliminate a reasonable fraction of this great tax pay for themselves in the course of a few years, even though they were originally expensive.

"In Pennsylvania the reduction of the typhoid fever death-rate has been marked in the ten-year period since the State Department of Health was organized and has resulted in the saving of thousands of lives to the State.

DEATHS FROM TYPHOID FEVER AND LIVES SAVED IN PENNSYLVANIA, 1906 to 1914, Inclusive.

Year.	Typhoid Deaths.	Rate per 100,000	Calculated Deaths. 1906 Rate Obtaining.	Saving as compared with 1906.
1906	3917	54.8		
1907	3538	48.6	3989	451
1908	2450	32.4	4064	1,614
1909	1712	22.7	4140	2,428
1910	1892	24.6	4216	2,324
1911	1716	21.9	4291	2,575
1912	1310	16.5	4367	3,057
1913	1470	18.1	4443	2,973
1914	1071	13.0	4518	3,447
Total saved				18,869

"In 1905, when the Department began its operations, Pennsylvania was a typhoid ridden state. The purification of the water supplies and the improvement in general sanitary conditions have been factors of tremendous influence in bringing about this marvelous reduction in the number of deaths from disease so often water-borne in origin." *

A further item of cost appears to be coming in the near future, namely, that of "*damages for the serving of unsafe water.*"

In April, 1915, the Supreme Court of New Jersey decided in favor of a plaintiff, awarding him expenses and loss of time because of the illness of three of his children from typhoid contracted from water supplied by the local water company. To quote from the decision:

"It must be borne in mind that the defendant company was in the water-supply business for profit. The plaintiff had paid for the supply which he was to receive in advance. Hence, it became the duty of the defendant company to give to the plaintiff water fit for domestic purposes, including fitness for drinking.

"Water is a necessity of life and one who undertakes to trade in it and supply customers stands in no different position to those with whom he deals than does a dealer in foodstuffs. He is bound to use reasonable care that whatever is supplied for food or drink shall be ordinarily and reasonably pure and wholesome."

Citation was made of a decision † "that pure and wholesome water necessarily means such as is reasonably free from bacteria and coli, or any other infection or contamination which renders water unfit for domestic use and unsafe and dangerous to individuals."

The court held that making it "reasonably appear that the drinking water was the probable efficient cause of the typhoid fever," was all that the plaintiff could be required to do.

In Wisconsin the supreme court has handed down a decision

* Pennsylvania Health Bulletin, Aug. 1915.

† Peffer v. Penn. Water Co., 221 Penn. 578; 70 Atl. Rep., 870.

in favor of an employee who died from drinking polluted water furnished him by a lumber mill company.*

In a paper by J. J. Hoppes he very tersely referred to the fact that the comparatively few deaths from typhoid fever in the army during the Spanish war had stirred up the newspapers to much comment and criticism, while they scarcely mention that 40,000 deaths from this disease occur annually in the United States, and many times that number of cases.

Americans insist upon being supplied with much more water *per capita* than is usually furnished in Europe, but they often are singularly indifferent as to its quality. It would be a reform of great moment if they could be induced to curtail the present enormous waste of public water, such as that of one New York city for instance, which is 70 per cent of the entire pumpage, † and to expend the money thus permitted to leak away in a vigorous effort to improve the quality of the supply. No such lowering of the typhoid death-rate as occurred at Munich, San Remo, and sundry other places could be looked for, perhaps, but a large percentage of the present rate could be cut off, and we think from a consideration of the above figures that such a reduction would pay.

No weight should be attached to the argument, so often advanced by the individual householder, that he and his family "have used the water without evil result for fifty years." A single family is too small a collection of units upon which to base any proper estimate touching the question at issue.

Placing the former typhoid death-rate for Albany, as above, at seventy-five annually, it would call for one death in a family of five persons every 261 years, a period much beyond the limits of ordinary family record.

This "*argument of experience*" is frequently used to defend well-waters whose purity has been questioned by the inspector. It must be remembered that a well which is polluted by "normal" sewage may furnish, during long periods of time,

* Vennen v. New Dells Lumber Co., Oct. 26, 1915.

† J. N. E. Water-works Asso., xiv., 212.

a water which is not disease-producing; and yet it may suddenly become very dangerous because of the introduction of infected sewage derived from a newly developed, and possibly imported, case of typhoid fever, or from the visit of some chronic " typhoid carrier."

A " typhoid carrier " is a person who, although apparently in normal health, nevertheless discharges bacilli of the disease in stools or urine or both, and who may continue so to do for a period of months or even years. Such a person acts as a sort of reservoir for the germs and is capable of widespread distribution of them. In fact it is now common to attribute to the action of " carriers " those instances of sporadic, obscure outbreaks of the fever which were formerly always cited as indicating a development of the *B. typhosus* from a non-typhoid parentage.

Data show that women are more prone to become " carriers " than are men in the ratio of five to one, an unfortunate fact in view of women being more closely connected with the preparation of food.

Of those who recover from typhoid fever about 3 to 4 per cent become " carriers " and remain so for varying and sometimes for long periods of time.

Out of 6708 typhoid patients examined in France, 310 became " carriers " for the following lengths of time:*

From $2\frac{1}{2}$ to 3 mos.	144	or	2.15%
" 3 mos. to 1 year	64	}	2.47%
" 1 year to 3 years	87		
" 3 years to $3\frac{1}{2}$ years	15		
	310		4.62%

The above periods of retention of the typhoid germ are occasionally greatly exceeded: Thus a case is reported of a woman who carried the bacilli for fifty-two years. Her general health was good except for more or less diarrhœa. In her

* Revue d'Hygiène Municipale, 6, 338.

capacity of boarding-house keeper, during the years 1905 to 1908, she gave the disease (presumably) to 159 of her boarders.*

It will be remembered that Mary Mallon (" Typhoid Mary ") was discovered by Soper in 1907. He secured evidence showing that this woman had, by her working as a cook, caused 28 cases of typhoid fever. "She was forcibly removed to a hospital, where an examination of her urine and fæces confirmed the suspicion that she was a typhoid carrier."

"Subsequently, in 1910, Mary was released on her promise not again to hire out as a cook and to use all precautions to prevent the occurrence of typhoid infections. She soon broke her parole, and at once the results were disastrous; two cases of typhoid fever occurred in a private sanatorium where she was employed. She went to the Sloane Hospital in October, 1914, and there followed in January and February an outbreak of twenty-five cases of typhoid fever among the physicians and nurses attached to the institution.

" The history of 'Typhoid Mary' gives point to the new sections of the Sanitary Code which forbid persons ill with infectious diseases to engage in the handling of foods sold to the public. It also emphasizes the importance of personal cleanliness, for, disgusting as it is, there is no doubt as to the probable path of infection.

" This dangerous carrier was again apprehended and detained by the Department of Health at Riverside Hospital on North Brother Island." †

"Doerr cites cases reported by Drober and Hunner, in which the bacilli were isolated from the gall bladder seventeen and twenty years after recovery, and Lentz asserts that if after ten weeks from convalescence the excretion of the bacilli has not ceased, it will most likely continue permanently and uninterruptedly, in spite of medication. He cites a number of cases in which ten, thirty, and even forty-two years after recovery the excretion continued." ‡

* Lancet, 195, 492.

† Bul. Dept. Health, N. Y. City, April, 1915.

‡ N. Y. State Board Health Bul., June, 1907.

"Carriers" are more dangerous in the country than in the city because of the greater chance of excreta getting in contact with food under country conditions. The enormous number of typhoid bacilli that may be discharged by a "carrier" has been determined by several observers. Petruschky found the urine to contain 172 million per cubic centimetre; and Gartner reports hundreds of thousands per gram of fæcal matter.

Although foreign to our topic, it may be well to state here that disease "carriers" are not limited in their activities to spreading typhoid fever alone. Sundry other diseases, notably diphtheria and cholera, are also distributed through such agencies. Nevertheless, the typhoid "carriers" command our closest attention and, until we can secure light upon some surely curative method of treating such persons, it would scarcely be a harsh order to prohibit their occupying themselves with the preparation of food. In addition to such an order, instruction should be given them, setting forth the danger they are to the health of the community and showing them how necessary it is that they should adopt strict cleanliness in their personal habits.

On March 31, 1916, a bill was introduced in the New York State Senate to provide for typhoid carriers, as follows:

"Whenever an individual is declared by the state commissioner of health as being a carrier of typhoid fever bacilli and whenever, for the protection of the public health, the state commissioner of health shall have certified to the necessity of continued quarantine; or, whenever, in accordance with rules and regulations adopted by the state commissioner of health a carrier of the germs of typhoid fever is prevented from carrying on any occupation which would enable him to gain a livelihood, such individual may be given hospital or institutional care under the surveillance of the local health officer at the expense of the state if such hospital or institution in the judgment of the state commissioner of health be properly equipped for the care and maintenance of said individual.

"When no such hospital or institution is available and when in the opinion of the state commissioner of health such indi-

vidual may be cared for at home or in a private family with due regard to the protection of the public health, the local charities commissioner or overseer of the poor shall, in accordance with rules and regulations adopted by the commissioner of health, furnish necessary medical attendance and maintenance."

Houston * considers the typhoid carrier as the great agent in the spread of the fever; he even terms such a person as the "home of the typhoid bacillus" and the "factory of the disease."

Concentrated doses of pathogenic bacteria are what we have to fear, for the reason that they overwhelm and break down nature's defence; and such heavy doses are, according to Houston, just what the "carriers" supply in contrast with what is furnished by the more "diluted" general sewage. He, in short, fears the unknown visitor more than he does the local community.

"In a large town there can hardly be any disproportionate number of 'carriers,' whereas when we are dealing with one, or only a few individuals of unknown health history the inclusion of a single carrier may enormously affect the disease-producing power of their combined excreta."

It is interesting to note that he believes one function of a municipal filter is that of breaking up collections of disease germs and causing separation of the individuals, thereby protecting the consumers from "concentrated doses" even if the germs should actually pass the filter.

It must be noted that there are some typhoid "carriers" who have no typhoid history. They have apparently never had the disease, and their tolerance of the *B. typhosus* has doubtless been secured by the repeated invasion of attenuated typhoid germs. They have slowly acquired a partial immunity against the disease by such an invasion, long continued. In this connection we note the difference between the susceptibility exhibited by persons long accustomed to the use of a polluted water supply and that shown by the non-acclimated stranger. In like manner we probably become, as we grow

* 9th Research Report Metro. Water Board.

older, gradually immunised against those "children's diseases" to which the young are so susceptible.

As has been already said, we should remember that when studying the extension of typhoid fever, or for that matter, disease in general, the power of the natural bodily resistance must be ever kept under consideration.

Certain invading organisms, that of plague, for instance, are so virulent in their attack that they are well nigh certain to break down nature's barrier of defence, and the lodgment of the germ becomes synonymous with the taking of the disease. Others, like that producing pneumonia, are very often carried about in the bodies of well people and require a decided lowering of "the power of resistance" before their pathogenic activities can become effective. Typhoid fever occupies a position between these extremes. Its invasion is a serious matter if its germs be vigorous and the "resistance of the subject" be low; but if the bacilli be attenuated or the resisting power of the subject be high, then the disease does not materialize at all, or the case developed is a mild one. Accepting it to be true that a disease is caused by the activities of a specific germ and that in the absence of the germ such disease cannot occur, and accepting it to be also true that a lowering of "resisting power" is frequently followed by outbreak of disease, then it follows that "unsuccessful invasion" must often take place. We are attacked and resist the attack more frequently than we appreciate.

An apparent increase in susceptibility is often observed during those typhoid epidemics which originate in the pollution of a city's water supply by the city's own sewage. In such cases the disease feeds itself, the sewage, and consequently the water supply, becoming progressively more infected.

Diarrhœal outbreaks of more or less intensity are frequently observed to precede epidemics of real typhoid, and they serve as warning flags of danger to come.

Having a shorter incubation period the milder disease develops first, and fewer people appear to be immune against its attack.

Sewage pollution of the water supply is commonly the reason for such disturbances of the public health, and it may be that typhoid will not follow if the cause of the trouble be removed in time.

Dr. Ball, of Warren, Pa., reports an outbreak of gastro-enteritis in 1906 which was unquestionably due to an infection of the water from a group of wells driven on an island in the Alleghany River. Suddenly, with no warning, some 1800 cases of the disease developed. There were no fatalities, but the cases were severe, often approaching collapse, and the illness lasted in most instances approximately thirty-six hours. The incubation period was about one day. Upon investigation there was found to be quite a direct connection between one or more of the wells and neighboring drains. There was no subsequent typhoid, but of course the source of the public water supply was changed.

Sedgwick reports a similar epidemic of diarrhœa at Burlington, Vt., from sewage pollution of the lake supply.

Thresh * gives an instance of a serious outbreak of diarrhœa caused by water from a service tank which was found to contain "many worms and other objectionable forms of small animal life."

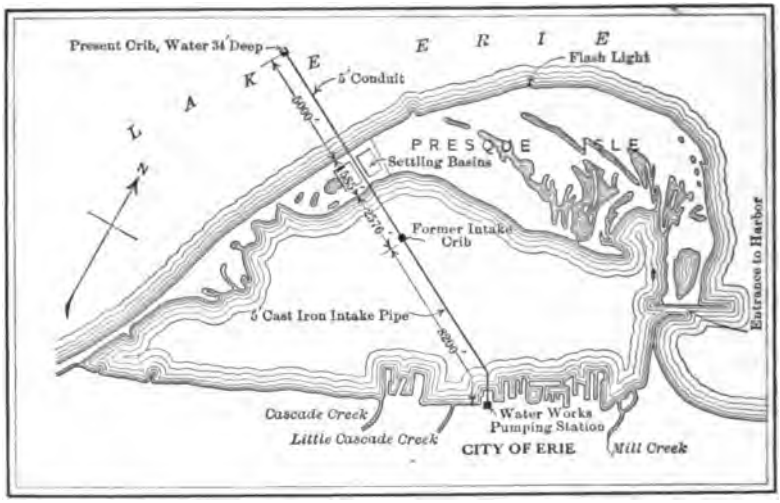
It is an unfortunate fact that these diarrhœal troubles do not, in most instances, terminate so fortunately as in the cases just given, it being more common for typhoid fever to follow hastily upon the heels of its less fatal forerunner.

Emergency intakes may be the means through which illness and death are spread broadcast throughout the community. The underwriters very naturally insist upon a sufficient fire service, which shall be available in the event of a temporary breakdown of the regular distribution system. It too often happens that upon such occasions a very inferior water is supplied by the "emergency intake." and as a result of its use there follows an outbreak of typhoid fever. Commonly, some old intake is allowed to remain in place for "emergency

* Exam. of Water, page 46.

service" when pollution of the former supply has so grown in intensity as to force the authorities to seek a new source for public water.

Further fouling of this old supply goes on progressively as population increases, until after some years the water becomes practically dilute sewage. Suddenly an accident to the regular water system induces the authorities to open the old gates, and the result may be imagined.



AT ERIE, PA., POLLUTED WATER ENTERED THE PUMP-WELL THROUGH A LEAK AROUND THE OLD INTAKE GATE NEAR THE PUMPING STATION. THE RESULT WAS A MOST SERIOUS TYPHOID EPIDEMIC.

Such has been the history of typhoid epidemics in a number of cities.

Thus at Butler, Pa., on October 20, 1903, the filtered water supply became temporarily unavailable and polluted water was admitted to the mains from a former river intake. A serious epidemic of typhoid fever followed, resulting in 1270 cases and 56 deaths.

Storage for a sufficient length of time, supplemented, if necessary, by an appropriate dose of bleaching powder, will render even a poor water acceptable for emergency uses,

and the reservoir capacity for such storage need not be large.

Abandoned intakes should be permanently cut off and water for emergency use should be drawn from a source the safety of which can be assured.

Vacation typhoid is a term used by not a few physicians to represent those cases of the disease which appear in the early autumn and which have been engendered by use of polluted water from badly located country wells, aided by sundry hygienic errors which are in contrast with the regularity of home life during the balance of the year.

Again we are reminded of the influence of unusual environment upon the "power of resistance," the same environment acting quite differently upon different persons.

"Recently studies of typhoid in India have shown that the maximum prevalence among the white troops is in the hot season as with us, while among the natives the maximum occurs during the cold and rainy months. This seems conclusive proof that the organism of the host is affected by abnormal and inclement seasons." *

Paratyphoid fever is a water-borne disease lately differentiated from typhoid fever proper.

"Although this is a less severe and less fatal disease than typhoid, it must be understood that the term is not applied to light cases of typhoid, but represents a distinct infection *sui generis*, probably caused by organisms intermediate between the typhoid and the colon bacillus."

"The absence of diarrhœa in the great majority of cases is one point of possible clinical differentiation from typhoid fever." †

During legal proceedings undertaken of late in connection with questions concerning damage to water supply, it was

* Winslow, Am. J. Pub. Hygiene.

† J. Infectious Diseases, Jan. 2, 1904.

suggested that "*anthrax*" should be held accountable for a portion of the trouble.

Anthrax spores are very resistant. Hastings has reported them to persist for eight years in pond water.*

In man the disease is commonly produced by the infection of a wound, even a small break in the skin being sufficient for the entrance of the spores. More rarely the conveyance is by flies, dust, or water, but human beings are more resistant to anthrax than are most animals and the number of cases due to ingestion is so small as to exclude it from serious consideration as a water-borne disease. Thus there were but five cases in all England during the five years 1899–1903.†

It must be admitted, however, that danger to stock does exist in the waters of streams that receive the industrial wastes from nearby tanneries, unless such trade effluents have been properly treated before admission to the stream. Heavy doses of chlorine added to the screened effluent will kill the anthrax spores. How much disinfectant should be used must be determined for each case, inasmuch as the quantity of organic matter present will to a certainty greatly differ with change in local conditions and consequently widely varying amounts of the chlorine will be rendered inert thereby.

New construction may temporarily greatly pollute a water passing through it.

Without careful inspection the worst kind of filth may be deposited in the very mains themselves by the thoughtless, careless employees at work upon the job; and even with the best supervision a newly-laid pipe or a newly-finished tunnel, or reservoir cannot be expected to be ideal in the matter of cleanliness.

Alvord reports that it was necessary at Gary, Indiana, to draw one hundred million gallons of water daily through the new tunnel for a period of twenty-one days in order to make the water safe for domestic use.

* Science, June 25th, 1909.

† See J. Roy. San. Inst., xxvii., 698.

At Troy, N. Y., when new connections were made with the Tomhannock tunnel, Diven secured the same results at less cost by the use of heavy doses of bleaching powder.

In view of the difficulty, so often encountered, of interpreting the terms found in many water contracts, it is well, before closing this chapter, to inquire

What is a "good, pure, wholesome" water?

Adjectives such as the above, with the occasional addition of the expression "clear," are commonly found in the contracts made by private water companies with the cities which it is their business to supply.

Litigation over an alleged violation of such a contract having been instituted, it usually becomes the duty of some expert witness to pass upon the question as to whether or not the water under consideration is of such a quality as to fall within the limits specified by the wording of the agreement.

To the average layman there would appear to be no ambiguity in describing a water as "good, pure, and wholesome," and he would see no objection to demanding that the words be descriptive of every public water supply in the country, and that the water companies, wherever located, be forced to live up to the exact and literal meaning of each and all of those words.

To show, however, that the above expressions are somewhat loosely used and that they lack in the definiteness which is expected of them, let us consider them separately for a moment.

What is a "good" water? Surely before answering we must inquire: "Good for what?" If for drinking, then its consideration would properly come later when we dwell upon the expression "wholesome." Outside of the question of potability, a water charged with calcium sulphate may be very "good" for the brewing of light ale and very "bad" for either boiler or laundry use. It is to the selenitic character of its water that Burton-on-Trent largely owes its reputation as a great

ale-producing centre, for the properties which are so popular in the brews of Bass and Allsopp seem to depend upon the presence of calcium sulphate in the water from which they are made. Such a water would, however, be very unacceptable to the large laundry interest of Troy, N. Y., where the daily soap-consumption is measured by the ton.

As with "good," so with the word "pure." It is, as used, quite ambiguous. Strictly pure water is a chemical curiosity, very difficult to prepare and perhaps still harder to preserve, as all know who have read about Sir Humphry Davy's classic determination of its composition. The word in the contract manifestly cannot mean water such as that; but if not, then what does it mean? If some permissible limit of impurity be implied, what is that limit and what is the character of the permissible impurity? These are fair questions, and they are pressing for an answer.

We turn now towards the expression "wholesome," trusting that here at least we have a definite term concerning which no misunderstanding can arise. It certainly does sustain more close scrutiny than the two already considered; but even this word, of apparently clear meaning, may be quite befogged by considerations that remind us of the old adage, "What is one man's meat is another man's poison."

How often we note that a change from a soft to a hard water, or *vice versa*, is followed by intestinal derangements, particularly among young children, a change of water being often nearly or quite as pronounced in its results as a change of air.

In view of this we begin to feel that Webster's definition of "wholesome" as "tending to promote health" may not strictly apply to the case in question; for it seems not unlikely that a shrewd cross-examining lawyer might very readily force the witness to admit that the water was "wholesome" for a part of the community only, namely, those who were acclimated, who had become tolerant to its use.

What has been said regarding change in hardness applies with equal force to variation in turbidity. In the stranger unaccustomed to its use, a turbid water will often produce a

transient form of intestinal disturbance. Shall we therefore declare such a water to be unwholesome? If so, our verdict would to a certainty be opposed by many thousands of people living in our great central basin.

Appreciating the two horns of the dilemma, the writer has adopted this position, namely, assuming the absence of sewage material and considering the silty turbidity alone, a somewhat turbid water is to be classed as undesirable for many purposes for which a city supply is used, but yet it cannot be rated as unwholesome, for the reason that it is unproductive of disease among the people for whose use it is primarily intended.

As we have seen, a water suited to the uses of one town might not be the best for the interests of another; or perhaps even a portion of a city might, because of its manufacturing establishments, desire a different water from that sought after by the residential section of the same community.

As a substitute for "good, pure and wholesome," the expression "safe and suitable" might be with advantage inserted in a water supply contract; and it is well to add here that the word "safe" alone will not suffice. Irrespective of its "safety" as regards disease production, a water should not offend the æsthetic sense. Few people would knowingly care to drink the effluent from a sewage disposal plant, and yet some such effluents taste and look like spring water, and some people actually do drink them. It is perfectly reasonable for the public to demand a "suitable" raw water and to insist that, however perfect the process of artificial purification, the raw supply shall not be derived from a source unduly foul.

A notable case in point is that developed during the "Chicago Stock Yards Water Purification Litigation." * The following is extracted from Johnson's report of that case:

"From a sanitary standpoint the whole case rested upon whether or not the waters of Bubbly Creek, primarily foully impure but purged by the purification process of all their visible impurities, and rendered clear and sparkling, but still

* Engr. News, Sept. 29, 1910.

containing in a dissolved state about 50% of the organic matter which the raw water contained, in the practical absence of bacterial life, and in the absence so far as bacteriological tests now can show of all bacteria commonly known as disease-producing forms, could still be considered a satisfactory water with which to water live stock.

"This filter plant was not constructed for the purpose of producing from Bubbly Creek a water supply for consumption by human beings. For some reason or other, as the trial progressed, the city pushed this phase of the question more and more to the front, until ultimately it was made to appear that, among other things, the company had installed this plant to render the waters of Bubbly Creek safe for human consumption, and that one of the final objects the Stock Yard Co. had in view was to substitute for the city water the effluent of the filter plant to be used throughout the yards for human consumption, as well as for watering live stock.

"Is water so badly polluted as that of Bubbly Creek a proper source of drinking water?

"This is a much-mooted question among sanitarians, but one which is far from being settled. Where the line may be drawn between polluted waters which may be rendered safe by filtration and sterilization processes and those which may not is beyond the writer's ability to indicate at this time.

"It is true that the waters of Bubbly Creek are much fouler than those ordinarily encountered in problems of water purification. The difference between the purification of such water and waters of far greater purity is, from a broad, practical standpoint, only a matter of degree.

"As to the effect on health of organic matter and its decomposition products in drinking water, the city endeavored to bring out the fact that, even though by the purification process the raw water was made pleasing to the eye and rendered practically free from bacterial life, the filtered product still contained dissolved organic matter in such quantities as would be likely to exert a toxic influence on persons drinking such water continuously.

"Anticipating that this contention would be raised the experts for the Stock Yards Co. considered carefully all of the available evidence bearing on this question. As a result the conclusion was reached, which conclusion was substantiated by the writings of numerous authorities on the subject, that in the absence of bacterial life organic matter is not injurious to the public health when consumed in such quantities as were found in the filtered water at the Union Stock Yards.

"One important witness testified in connection with this question that:

" 'From my experiments I concluded that substances which are to be considered harmful are not present in the filtered water.'

"In his cross-examination this point was again brought up as follows:

" 'Q.—What limit would you consider as the amount of organic matter that might be in water which was practically sterile so far as bacteria are concerned?

" 'A.—I could not give any exact limit, but undoubtedly a larger amount of organic matter than we have in this case would still be within a reasonable limit.'

" 'Q.—Do you consider that organic matter that comes from sewage is not more harmful than water which has organic matter in it that comes from decayed vegetables?'

" 'A.—When you are talking about water purification, there is absolutely no difference in it. The protein matters are the same. It is a well-established fact that they yield the same decomposition products.

"Attention is also directed to the evidence given by another witness, who in this connection testified on cross-examination in this case as follows:

" 'Q.—If you were to select a water supply for a community and have the two sources of supply, Bubbly Creek, with this filtration plant as operated, and Lake Michigan, with the water that we could get from Lake Michigan, in the shape that it is in, would you recommend the Bubbly Creek supply instead of the Lake Michigan supply?'

" 'A.—I should say that it would be more safe and usable than the other. Yes.' "

Inasmuch as the people usually know whence it is proposed to take the water, would it not be wisdom to place in the contract some form of definite analytical specification, whereby the water, as offered to the consumer, could be held up to the quality established by an accepted local standard.

In conclusion, let a word be said about a matter that has recently awakened no small degree of general interest.

It would seem that the attention of the public has been largely drawn of late to the question of the wholesomeness of distilled water for dietetic purposes, numerous articles having issued from the press under such captions as "Poisonously Pure Water" and the like.

Much uneasiness has been created among those who have substituted the use of distilled water for domestic purposes, in place of some supply of acknowledged impurity, because of their being told that "distilled water is an active protoplasmic poison, due to its property of extracting salts from animal tissues and causing them to swell up by imbibition."

Stress is, of course, laid upon the increased danger arising from the use of such water by the young, whose tissues are in process of formation.

Surely it is only fair to insist that the burden of statistical proof be borne by those who advance this proposition, and until such data are furnished we will rest our faith upon such facts as the following:

The Croton water supply of New York City contains 5.48 grains of solid matter per U. S. gallon, or 1.37 grains per quart.

One quart of water per day for a child would be a liberal allowance, considering that milk is also a portion of the diet.

In consideration of the mixed character of human food, and the amount of mineral salts naturally occurring therein and added thereto, the withdrawal of 1.37 grains of mineral salts per day, by the substitution of distilled water for that

drawn from the Croton River, would be a matter of too small importance for consideration.

Finally, let it be remembered that all the vessels of our navy condense their drinking-water by means of the Baird condenser, and the navy medical authorities report most excellent results. Surely the bone and muscle of the "men behind our guns" speak for themselves.

In a letter to the author, Surgeon-General W. C. Braisted of the U. S. Navy says: "The use of distilled water on ships of the Navy has always tended to the very best of health conditions. In my opinion the use of distilled water offers the ideal drinking fluid for human consumption."

It may be interesting to add that "the Marine battalion, some five or six hundred strong, used distilled water from the ships all the time they were doing shore duty at Guantanamo, Cuba, and they had none of the enteric fever that prevailed so extensively in the Fifth Army Corps."

CHAPTER III

ARTIFICIAL PURIFICATION OF WATER

To comprehensively cover so broad a subject as is indicated by the heading of this chapter would call for a series of monographs rather than the short space that can be here devoted to it. Water purification has become a special art that has been again divided into sub-specialties, each with its own experts and an extensive literature.

It must be accepted as an axiom that pure water is better than purified water, but pure water is becoming more and more difficult for many of our towns to secure, so that the best that some of them can hope to obtain is a polluted water which has been efficiently purified by art. It is a question, sometimes, whether it would not be better policy, considering the rapid changes in the density of population, to accept a moderately polluted source and thoroughly purify its water, rather than go to large expense in obtaining a faultless supply which might have to be purified in its turn at some later day.

It is hopeless and unreasonable to expect an up-stream community to so purify its sewage and otherwise protect the water of a stream which it has a right to use, as to deliver its water to the down-stream neighbor "undiminished in quantity and undamaged in quality." The common law may order such neighborly action, but the demand is both impracticable and unfair. Inasmuch as the lower city should, in any event, erect purification works to care for its water supply, it would be unjust to require those living higher up to attempt the conversion of their sewage and trade-waste into drinking water before turning the effluent into the stream. The burden of improvement should be divided, and all that could in fairness be

asked should not go beyond so protecting the water of the stream as to permit of its being delivered to the water-works intake in such condition as to allow of its being used without undue difficulty or expense, as a "raw" water for modern purification works.

And that brings up the question, How bad must a water be to require its exclusion as being unfit for a "raw" supply? No definite reply can be made. If necessity demanded it, and expense were not considered, a water safe for drinking purposes could doubtless be prepared from sewage itself. It is difficult to conceive of a raw supply much worse than that of Bubbly Creek, Chicago, and yet an attractive water is the output of the purification plant used to improve it.

The poorer the raw supply the greater is the risk of trouble following careless handling or temporary inefficiency of the purification works. A sensible rule to follow is to select the very best source of supply available and then improve the same, if necessary, by the most reliable process suited to the needs of the case.

Outside of any question of wholesomeness, the water which a part of our people are content to use at present may not be considered suitable in a few years to come. The tendency is towards a general demand for a clear and colorless water, and water-purveyors must be prepared to meet it.

Filtration of surface water, before delivering the same for public consumption, is now specifically ordered by the laws of Germany, and rules are laid down for its proper accomplishment. Such legislation is not improbable in this country, thus still further making it the part of wisdom to anticipate the artificial improvement of some waters which are now possibly considered beyond impeachment.

The art of removing suspended material from water by some form of filtration has been known during many ages, although it was not put into extended practice until very recent times; thus the siphoning of liquid from one vessel to another by the capillary action of porous material, such as a strip of cloth, and the consequent separation of the liquid from sus-

pended material, was well known to the ancients and is frequently mentioned.*

The modern methods of filtration claim to do something more and better than merely to strain off the grosser elements of turbidity; and so fully do the people of Europe appear to believe this claim a just one that with them a city water-works without an attendant filter-plant is becoming almost a novelty. The method of purifying water on the large scale which deserves first attention on account of its early use and wide application is that of "slow sand filtration," commonly known also as

THE ENGLISH FILTER-BED SYSTEM

Briefly described, an English filter-bed is a tight reservoir, containing some five or six feet of stratified filtering material, of progressive degrees of fineness, beginning at the bottom with broken stone or gravel, and ending with an upper layer of fine sand, the whole being suitably underdrained.

Much diversity exists in the relative thickness of the several layers, some filters being constructed with a very thick upper layer of fine sand, while with others the finest material is put on as a comparatively thin cover. The Dutch filters are especially marked in the thinness of their beds,† a feature by no means to be recommended; for, although much of the actual work of filtration is done by the upper layer of sand, yet, if the thickness of the body of the bed be unduly reduced, that portion of the water which is in the act of being delivered will bear too large a ratio to that filling the interstices of the coarser layers; as a result, currents will be established and ruinous channelways be quickly worn in the uppermost stratum.

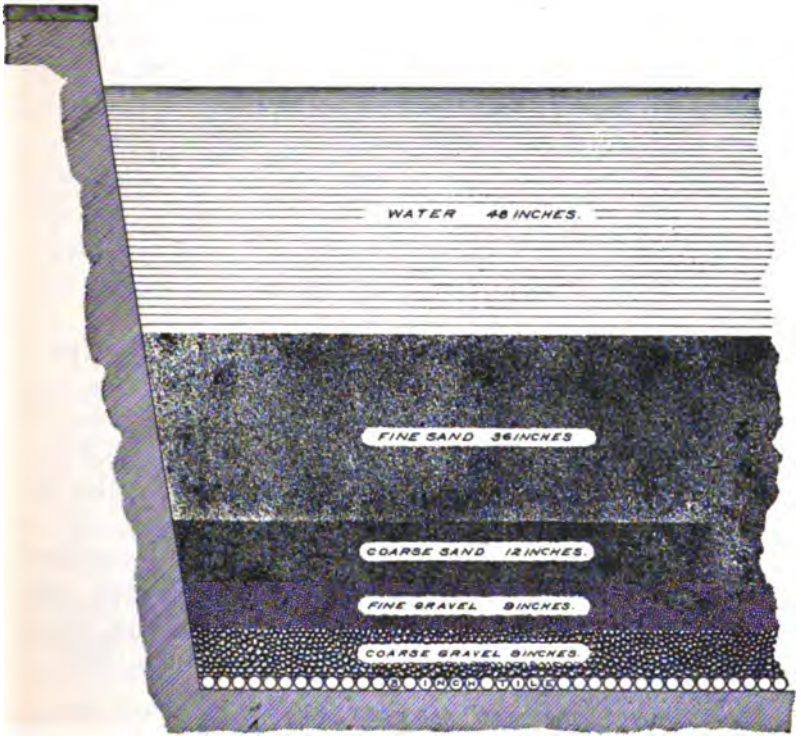
Through the fine-sand layer the water slowly and evenly passes, leaving the bulk of its suspended impurities upon the surface to form the *Schmutzdecke*, or "dirt cover," of the Germans.

Beyond the mere gradual accumulation of suspended matter strained from the water, this *Schmutzdecke* is in part composed

* Bolton, "Ancient Methods of Filtration," Pop. Sci. Monthly, xvi., 495.

† Mr. Halbertsma informs the author that the height of the ground-water level is one reason for the thinness of the beds.

of slimy, jelly-like material, produced through bacterial agency, which serves to entangle and hold bacteria and other suspended substances of all kinds.



SECTION OF AN ENGLISH FILTER-BED. SOUTHWARK & VAUXHALL WATER CO., LONDON.

COMPOSITION OF VARIOUS FILTER-BEDS, IN INCHES

	Fine Sand.	Coarse Sand.	Fine Gravel.	Medium Gravel.	Coarse Gravel.	Small Stones.	Large Stones.	Total Depth.
Berlin	22	2	6	5	3	4	12	54
Zurich	32	6	4	.....	6	.....	.....	48
London, Southwark and Vauxhall	36	12	9	.....	9	.....	.....	66
Poughkeepsie, N. Y.	24	.....	.....	18	.....	6	24	72
Hamburg	40	.....	.....	24	.....	.....	.....	64
Albany, N. Y.	48	.....	2½	2	6	.....	.....	58½
Roxborough, Phil., Pa.	36	1	5	4	6	.....	.....	52
Pittsburgh, Pa	48	1½	.....	2	3½	5	.....	60

It must not be thought, however, that the extreme top layer of sand, with its cover of slime, does the entire work, so far as purification is concerned. Each of the sand grains of the body of the bed becomes covered with a sticky coating of the zoöglœa jelly, and they collectively are to be credited with a large share of the results accomplished. This is shown by Reinsch, who has published his observations of the Altona filters. He found the unfiltered water to contain 36,320 bacteria per cubic centimetre. After passing the slime layer there yet remained 1876, but after going through the entire depth of sand there were found but 44 per cubic centimetre. Thus the lower layers have uses other than mere regulation of flow.

A filter recently disturbed by the process of cleaning is lower in efficiency than one which has been for some time in operation. In fact it might be properly described as "at its best when at its dirtiest"; and, were it not that it finally becomes almost impervious to water, it would be better not to clean it at all. A new filter is of small use until it "ripens" for work; that is, until the "nitrifying" organisms have firmly established themselves and the zoöglœa jelly envelops the sand grains. We have here an additional reason for a thick sand layer which will permit more of the filter to rest undisturbed.

The *thickness of the sand layer*, for proper working, should be made not less than thirty-six inches, and this depth should not be permitted to greatly decrease, by reason of the successive removals of layers of the upper surface for purposes of cleaning. At Albany the thickness of the fine-sand layer is not allowed to fall below the limit of two feet.

The head lost in passing the filter naturally increases as the sand becomes clogged, and the rapidity with which this loss occurs will of course vary with the character both of the bed and of the water being filtered. When this loss of head reaches four feet at the Albany plant the filter is shut down for cleaning. Such figure is a common one.

The engineering structures containing these layers of filtering materials differ from one another in size, in shape, and in method of construction, according as the preference of the designer may dictate or the necessities of the case may demand. In London it has been common to select one acre as the proper superficial area of a filter-bed. The Hamburg filters are each 1.89 acres in area; those constructed at Albany, N. Y., are each seven-tenths of an acre, while the areas of the individual beds at Philadelphia (Roxborough) and Washington are one-half and one acre respectively. Usually the inner wall-surface is nearly, or quite, vertical, but the Holland filters (see page 122) form a notable exception in this particular, having a slope, at times, of more than one to one.

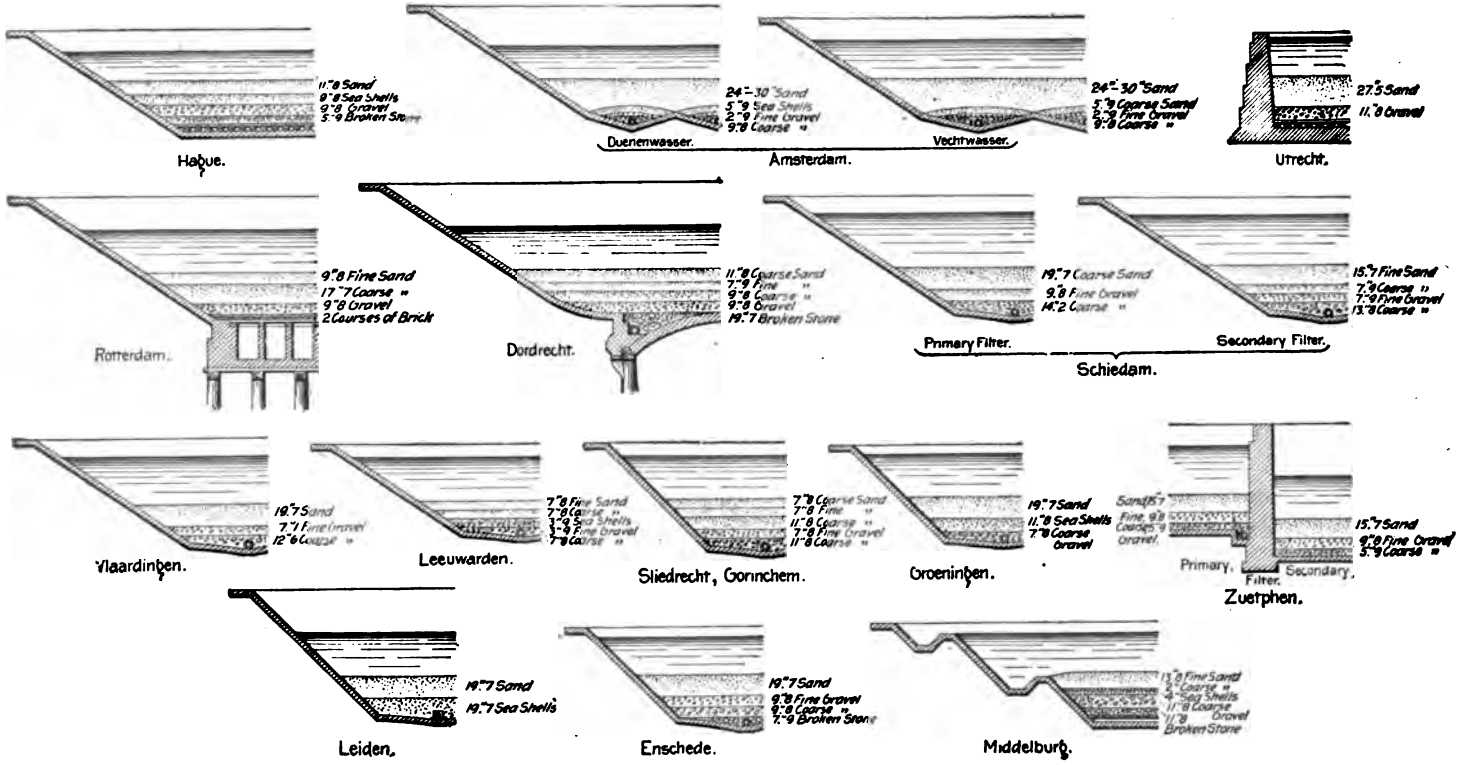
An objection to an entirely vertical wall is that there is possibility of improperly filtered water passing down between it and the sand. A wall having some slope or one broken into steps affords a better opportunity for a good joint being made with the filtering material.

As to composition, the body of the side walls is as varied as one would expect to find it among reservoirs in general, running from earth embankments with clay puddle cores to structures of pure concrete, or even of dressed stone. Such as are constructed of earth are, however, carefully protected on the inside, by suitable paving, from the damaging action of ice and waves.

Some of the filters of the Southwark and Vauxhall Company (London) have a layer of three-inch agricultural drain-pipe, placed side by side with open joints, over the entire bottom, thus securing easy flow to the clear-water reservoir. (See illustration, page 119.)

In the Albany plant these are replaced by lines of six-inch vitrified pipe, open-jointed, and laid thirteen feet eight inches apart.

A convenient form of hollow-tile underdrain has been invented by L. K. Davis. It is easily understood by reference to the illustration on page 125.



SECTIONS OF DUTCH FILTER-BEDS. (After Halbertsma.)

Covers for filter plants add greatly to the expense and, in mild climates, the increased cost may not be warranted, but in those localities where the winters are severe it becomes necessary to throw over them a cover, which is commonly of concrete, resting upon columns of the same material.

Thick ice renders it practically impossible to properly clean a filter by the ordinary methods, and the resulting imperfect purification of the filtrate is often coincident with increase in the death-rate. This was noted in Berlin in the winter of 1889, when an outbreak of typhoid fever followed the deficiency in purifying power of the open filters. That portion of the city supplied with water from the covered filters was not visited by the epidemic.

Protection against ice is not the only advantage offered by the cover, however, Heavy growths of algæ may occur in the water of an open filter, with serious clogging of the sand. The writer has seen filters in England so blocked by growths of *Mougiotia* that until the matted masses were removed practically no water could pass the sand. Exclusion of sunlight prevents such growths.

Increased difficulty of cleaning is not worthy of consideration as an objection to covers, for with modern methods both open and covered filters are cleaned with equal facility.

When it is a doubtful question whether or not covers will be necessary, it is good policy to put in the foundations for the piers necessary for their support so that later the covers, if required, may be added without undue expense.

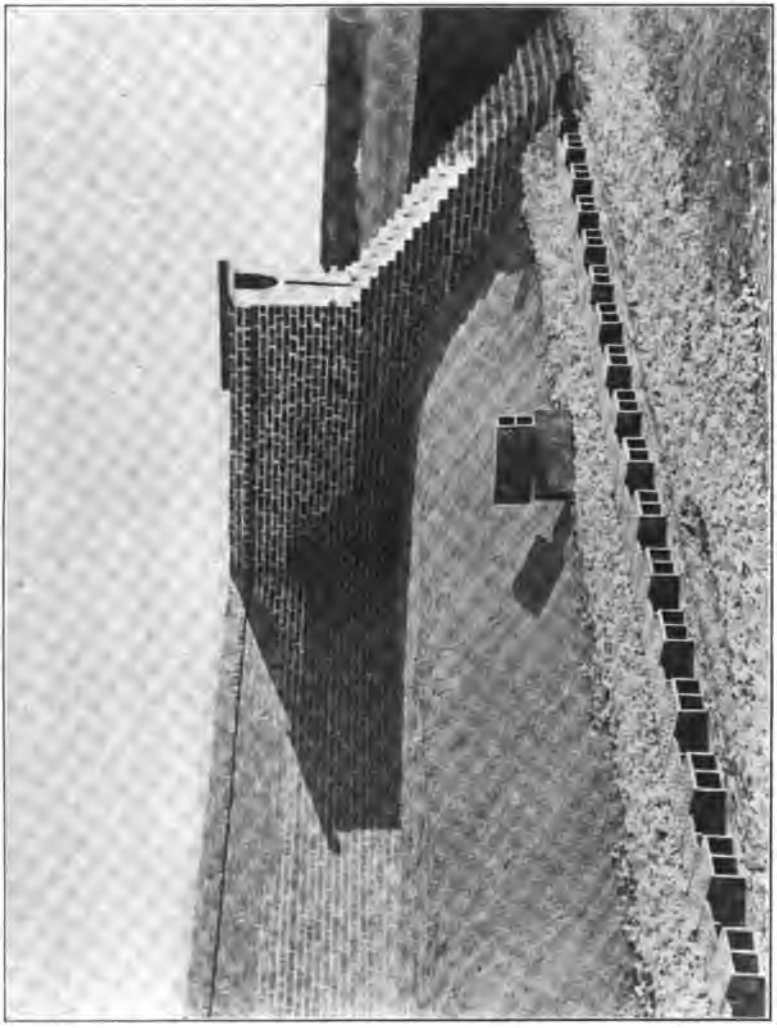
In England the climate does not demand the construction of covered filters as protection against frost, as much trouble from ice is not experienced; but even there exceedingly cold weather will at times occur, bringing with it large additions to the bill for expenses of maintenance. A notable winter in this particular was that of 1884, when seventy men were constantly employed in removing ice from the Southwark and Vauxhall beds. (See illustration, page 124.)

Mr. Allen Hazen, in his excellent work on "Filtration of Public Water-supplies," advocates the covering of filters in

REMOVAL OF ICE FROM LONDON FILTER-BEDS.

all localities where the mean January temperature is below the freezing-point.

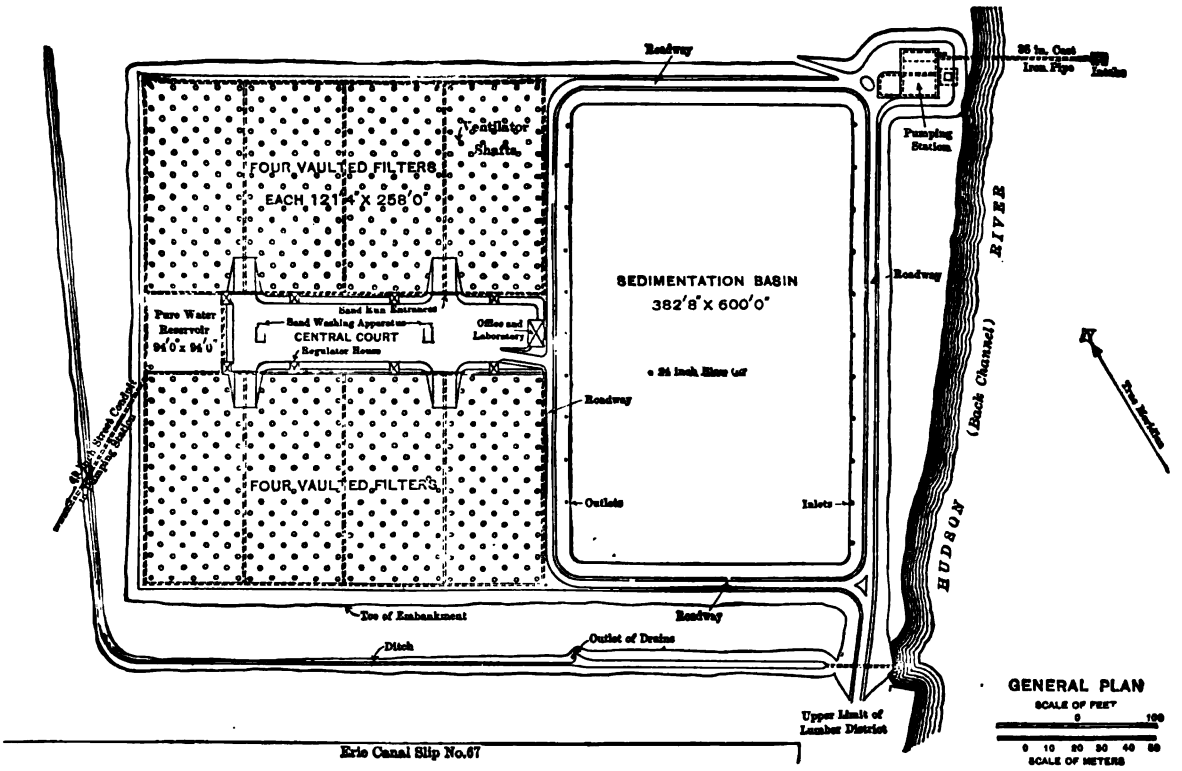
An idea of the interior appearance of a covered filter may



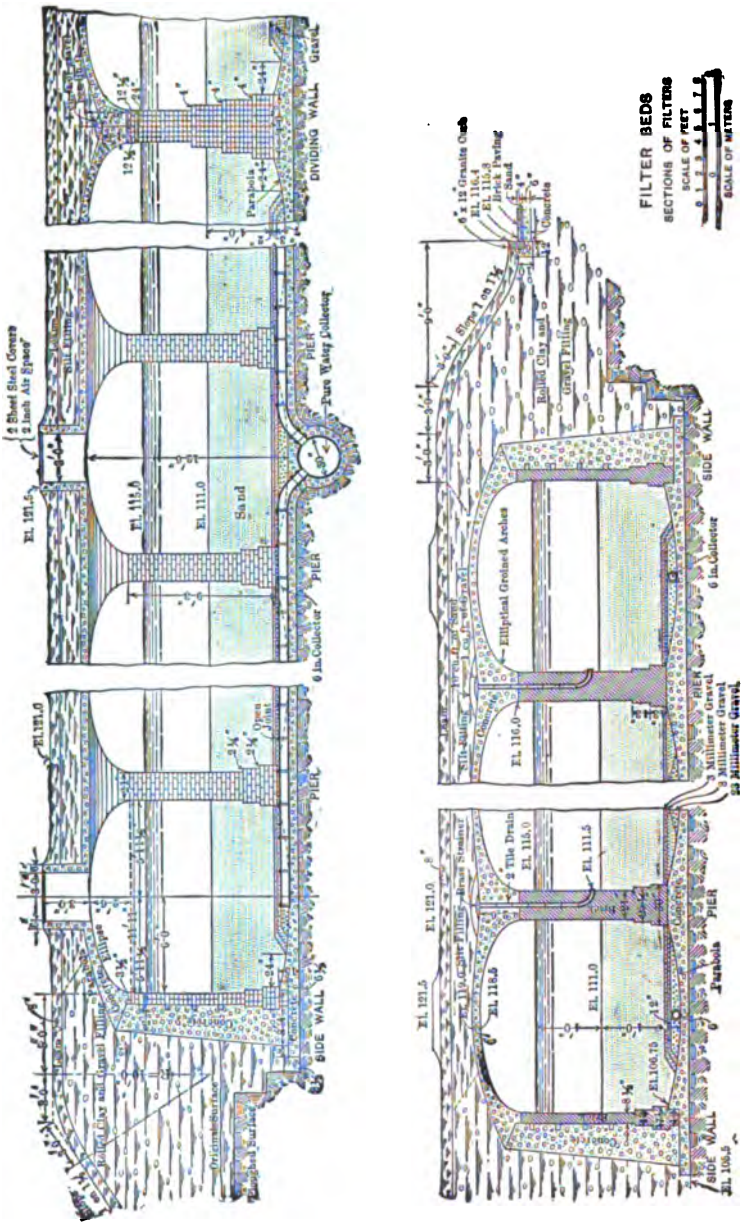
PERFORATED TILE UNDERDRAINS. (Devised by L. K. Davis.)

be obtained from the cut on page 129 showing a filter belonging to the plant at Ashland, Wis.

The illustraton on page 130 is from a photograph showing



FILTERS AT ALBANY, N. Y. (Hazen.)



ALBANY, N. Y., FILTER-BEDS. (After Hazen.)

the covered beds at Zurich, Switzerland, in process of construction.

As is well known, London filters all of its water, with the exception of what is derived from deep wells in the chalk. Certain statistics relating to these plants are here given.*

Name of Company.	Source of Supply.	Daily Supply in U. S. Gallons.	Number of Filter-beds.	Total Area of Filter-beds. in Acres.	Depth of Filter materials.
Chelsea.....	Thames river.....	12,727,000	7	6¾	8 ft.
East London...	Thames river Lee river Chalk wells Springs	51,495,000	31	29¾	3 ft. 6 in.
Grand Junction	Thames river.....	22,391,000	15	17¾	5 ft. 6 in.
Kent.....	Deep Chalk wells...	17,126,000	none		
Lambeth.....	Thames river.....	23,509,000	10	9½	7 ft.
New River....	Chadwell spring Lee river. Chalk wells	43,190,000	20	16½	5 ft. 7 in.
Southwark and Vauxhall....	Thames river.....	34,080,000	12	14½	5 ft. 6 in.
West Middlesex	Thames river.....	21,627,000	12	15	5 ft. 6 in.
Total...	.....	226,145,000	107	109¾	

The cost of constructing a filter-bed upon the general plan described must necessarily greatly vary, in direct ratio, with the local cost of labor and materials, and with the difficulty of the engineering problem involved.

For some well-known plants the cost of construction is given, as follows, exclusive of the price of land:

London.—A bed one acre in filtering area costs from $24,000 to $39,000, depending on the nature of the ground. Those of the Southwark and Vauxhall plant each cost the latter sum. All these beds are uncovered.

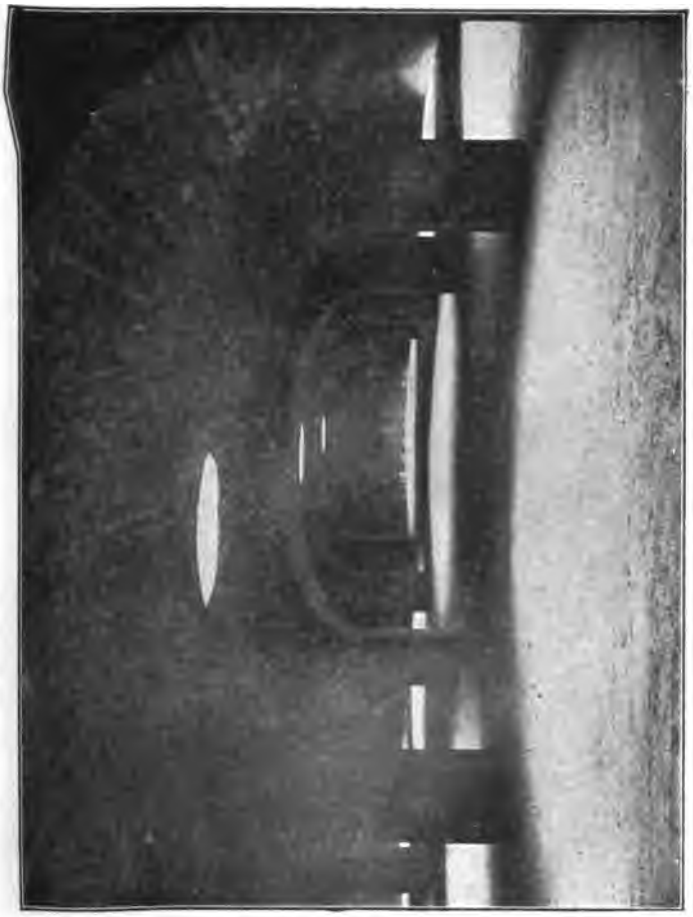
Liverpool.—Same as London.

Zurich.—Covered beds, complete, cost 120 francs per square metre of filtering surface (about $2.25 per square foot, or

* For further information see "The London Water-supply," by Shadwell.

$98,000 per acre). The uncovered beds, previously in use, cost two-thirds of this sum.

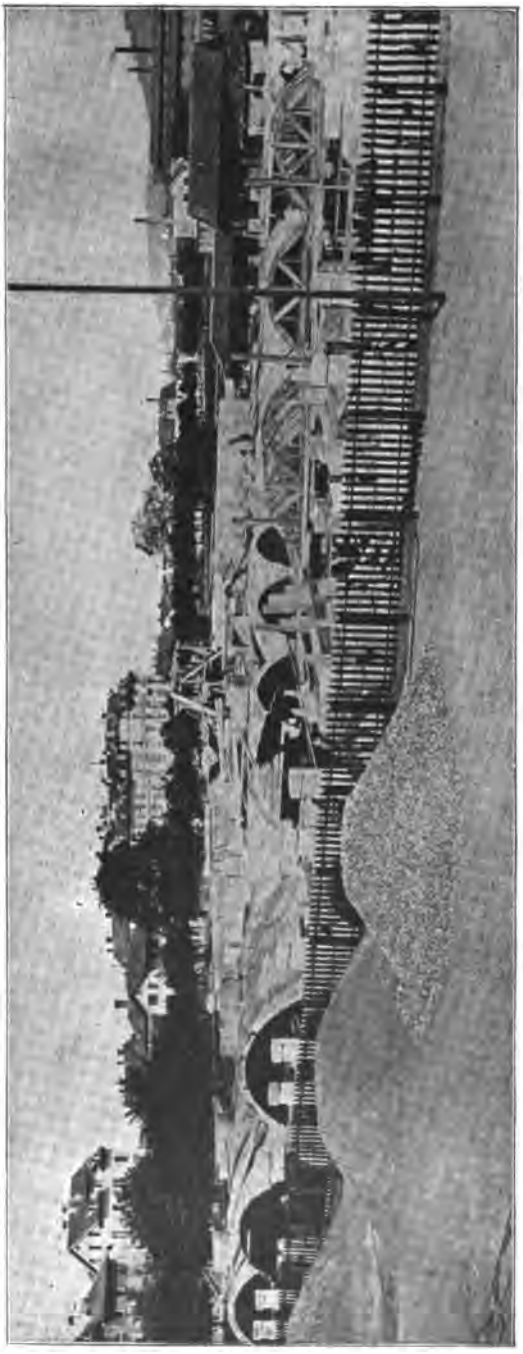
Hamburg.—The filters when first built (open), cost 33 marks per square metre of sand-surface (about 70 cents per square foot, or $30,500 per acre).



A COVERED FILTER AT ASHLAND, WIS.

Berlin.—The covered filters cost $70,000 per acre, and the open ones about two-thirds that sum. Lindley gives a general estimate for the Continental filters, as follows: Open, $45,000 per acre; covered, $68,000.*

* See also Engineering News, Aug. 16, 1894.



COVERED FILTER-BEDS AT ZURICH, SWITZERLAND, UNDER CONSTRUCTION.

Ashland, Wis.—The beds are three in number; they are covered and of one-sixth of an acre each. The complete cost was at the rate of $70,000 per acre.*

Albany, N. Y.—The filters are eight in number, of concrete, with vaulted covers, also of concrete. Cost per acre, $45,600. This does not include the pre-filters or "scrubbers" since added. Miscellaneous data concerning these beds will be found on page 144.

Mr. G. W. Fuller gives the following (complete) costs per acre:

Augusta, Me	$94,534
Pittsburgh, Pa	72,777
Philadelphia (Queen's Lane)	71,550
Washington, D. C	74,000

An approximate idea of the cost of some older filter-beds may be obtained from the estimates given by Mr. Edmund B. Weston in a paper in the *Engineering News* of October 7, 1897.

Covered with masonry vaulting, cost per acre	$70,000
Uncovered, cost per acre	38,892

These estimates do not include the cost of a sedimentation-basin.

In Mr. Hazen's opinion covered filter-beds should be roughly estimated as costing $15,000 per acre more than those which are open.†

Sedimentation-basins are essential in all cases where the water to be filtered is materially turbid. These basins need not be of great size. Storage sufficient to equal the twenty-four hours' supply is quite enough, for in that time the great bulk of the suspended material will settle, and the balance can be economically removed by the filter. Where no settlement is permitted before running a turbid water upon the filter,

* J. N. E. Water-works Asso., xi., 314.
† Engineering News, Jan. 24, 1902.

an unnecessarily rapid clogging of the sand results, with consequent increase in frequency of cleanings.

A clear-water basin is required to receive the filtrate from a filter plant, in order to provide for fire emergency. One capable of holding eight hours' supply is sufficient. Under special circumstances, as when large storage of filtered water in service reservoirs is available, the clear-water basin may be made smaller. That at Albany, N. Y., holds only 600,000 gallons, or less than one hour's supply.

When a battery of several filters is under construction, it is very desirable that the separate beds be so arranged as to permit of the flow being watched from each one individually, otherwise the general filtrate might be damaged by the poor working of a single member of the group, and no means would exist of detecting and remedying the evil.

In a paper before the American Water Works Association. March, 1914, Mr. G. A. Johnson gave sundry figures for comparative "first cost" and "cost of maintenance" of slow sand filters and "rapid" or "mechanical" filters (to be described later).

"In discussing the cost of building water filtration works of the slow sand and rapid sand types, respectively, consideration will be given only to those items referring to the filter plant proper. Cost of land, pumping machinery, outside connecting piping, intakes, etc., in fact everything outside the filtration plant proper, will not be considered.

"For slow sand filter costs the items will include the necessary filter buildings and filters with all appurtenances, all inside piping, sand handling apparatus, preliminary sedimentation basins, preliminary filters and appurtenances and clear-water reservoirs.

"For rapid sand filter costs the items will include the filter buildings and filters with all appurtenances, all inside piping, filter washing apparatus, coagulating and clear-water basins. Thus a fairly good idea may be had of the relative cost of building purification plants of the two types.

"It is true that, on account of the much greater area required, the cost for land is far greater in the case of slow sand filtration systems than for rapid sand systems. Roughly, other things being equal, land will cost twenty times as much for a slow sand filter installation as for a rapid sand plant. Furthermore, in large projects, it is often difficult conveniently to locate a site for slow sand filters, while for a rapid sand filter plant it is a relatively easy matter as a rule. If it is necessary to go a long distance in locating an extensive and suitable area of land for a slow sand filter site there is incurred a large expense for a conduit to bring the filtered water to the city. This is very rarely necessary in the case of rapid sand filter projects. So that, in studying the comparative figures which follow, it must distinctly be borne in mind that the costs given for slow sand filter installations are really low, since the important considerations just mentioned are not charged against them.

COST OF OPERATION AND MAINTENANCE OF SLOW SAND AND RAPID SAND FILTRATION PLANTS

Year.	City.	Kind of Filters.	Average Volume of Water Filtered Daily. U. S. Gallons.	Cost of Operation and Maintenance per Million Gallons of Water Filtered.
1911	Albany, N. Y.....	Slow sand	20,000,000	$2.50
1912	Pittsburgh, Pa.....	Slow sand	100,000,000	3.41
1911	Philadelphia, Pa.....	Slow sand (*a*)	9,000,000	5.62
1911	Philadelphia, Pa.....	Slow sand (*b*)	13,000,000	3.59
1911	Philadelphia, Pa.....	Slow sand (*c*)	38,000,000	3.88
1911	Philadelphia, Pa.....	Slow sand (*d*)	202,000,000	1.91
1912	Washington, D. C....	Slow sand	62,000,000	4.01
1912	Cincinnati, Ohio.....	Rapid sand	50,000,000	4.12
1911	Harrisburg, Pa.....	Rapid sand	9,000,000	3.93
1912	Little Falls, N. J.....	Rapid sand	30,000,000	3.20
1912	Louisville, Ky.....	Rapid sand	25,000,000	3.48
1912	New Orleans, La.....	Rapid sand	16,000,000	6.32
Weighted average.....		Slow sand	.....	$2.86
		Rapid sand	.....	4.04

(*a*) Lower Roxborough; (*b*) Upper Roxborough; (*c*) Belmont; (*d*) Torresdale.

"COST OF CONSTRUCTION OF SLOW SAND AND RAPID SAND WATER FILTRATION PLANTS

City.	Kind of Filters.	Present Daily Filtering Capacity. U. S. Gallons.	Approximate Cost per Million Gallons Daily Capacity.
Albany, N. Y.	Slow sand	20,000,000	$20,000 (a)
Pittsburgh, Pa.	Slow sand	200,000,000	26,000 (a)
Philadelphia, Pa.			
Torresdale	Slow sand	250,000,000	37,700 (a)
Upper Roxborough	Slow sand	28,000,000	29,800
Lower Roxborough	Slow sand	17,000,000	26,300 (a)
Belmont	Slow sand	60,000,000	45,200 (a)
Washington, D. C.	Slow sand	100,000,000	30,000 (b)
Cincinnati, Ohio	Rapid sand	112,000,000	11,400 (c)
Columbus, Ohio	Rapid sand	30,000,000	13,000 (d)
Dallas, Texas	Rapid sand	15,000,000	13,000
Harrisburg, Pa.	Rapid sand	16,000,000	10,300
Little Falls, N. J.	Rapid sand	32,000,000	15,000
Lorain, Ohio	Rapid sand	6,000,000	14,000
New Milford, N. J.	Rapid sand	24,000,000	11,000
Watertown, N. Y.	Rapid sand	8,000,000	11,250
Weighted averages	Slow sand	.....	$32,600
	Rapid sand	.....	12,100

(a) Cost of preliminary filters included.
(b) Cost of Dalecarlia Reservoir not included. Cost of McMillan Park Reservoir included, and also cost of remodeling Georgetown Reservoir, as well as cost of coagulating basin.
(c) Cost of large plain sedimentation basin not included.
(d) Cost of softening works not included.

"The above figures show that the approximate relative cost of building the slow sand and rapid sand filter plants mentioned was $32,600 and $12,100 respectively, per million gallons daily capacity. At 5 per cent the fixed charges on these sums would amount to $4.47 and $1.66, respectively, per million gallons of water filtered.

"The cost of operation and maintenance of filtration plants in a large measure, varies, of course, with the quality of the raw water. In a general way the following examples will serve to show the charges ordinarily made against the operation and maintenance of representative water filter plants in this country.

"To summarize, the average cost of buildings even of the largest and most modern slow sand filter plants was $32,600

per million gallons daily capacity; and, likewise, the average cost of building six of the largest, and two medium size, rapid sand filtration plants was $12,100 per million gallons daily capacity. The average cost of operation and maintenance varied widely, of course, but averaged $2.86 and $4.04 per million gallons of water filtered by the slow sand and rapid sand systems, respectively. Adding these last figures to the fixed charge on the first cost of construction makes up the following totals:

Slow sand filtration	$7.33 per million gallons
Rapid sand filtration	5.70 per million gallons

The depths of water permitted upon filters of the slow sand type are almost as various as the compositions of the beds themselves.

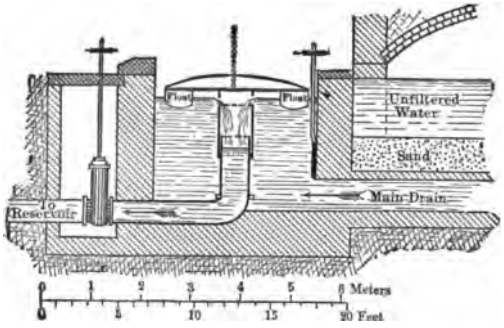
Three and a half to four feet of water may be taken as the depth most commonly in use, and it is important that this depth, when once determined upon, should be maintained a constant. In one of the older filters of this country the head of water varied exceedingly, running from a few inches to over six feet. Such inequality as must result in the rate of filtration cannot but cause wide differences in the purity of the filtrate.

With the more modern filters the rate of delivery of filtered water is more independent of the depth of water on the sand, being controlled by an effluent regulator. A form devised by Lindley for the Warsaw works and shown herewith will serve to illustrate the principle. The outflow takes place through the horizontal slits under a head which is maintained constant by means of the floats attached to the upper end of the cylinder which telescopes the fixed outlet.

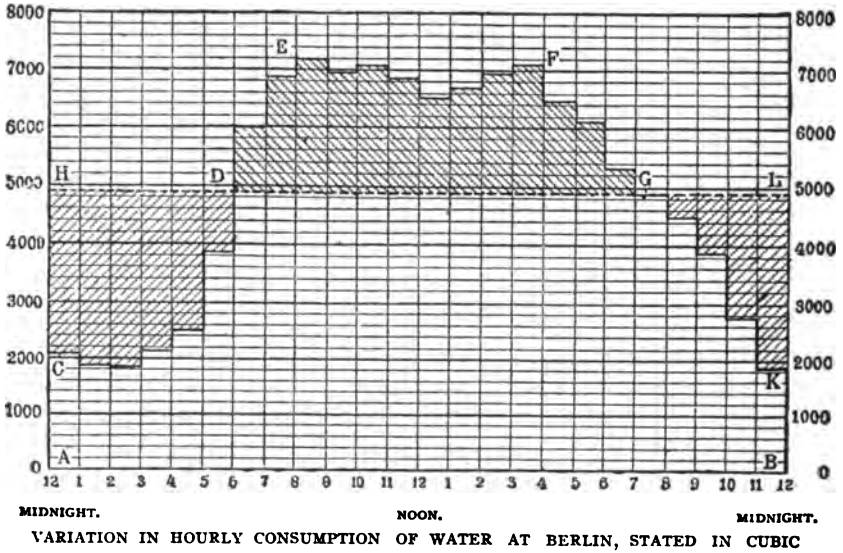
By use of some such device as Lindley's, associated with a simple overflow-pipe to correct errors from too deep flooding of the bed, constancy in rate of filtration can be assured, a point of material importance in the proper management of a filter.

The rate of filtration usually adopted in the past and still commonly in use is three million U. S. gallons per acre of

sand surface per twenty-four hours. That is the figure generally held in mind when planning a slow sand filter, but the rate may be pushed to double that quantity if the character of



EFFLUENT REGULATOR. (Lindley.)



VARIATION IN HOURLY CONSUMPTION OF WATER AT BERLIN, STATED IN CUBIC METRES. (Frankel.)

the raw water, or its previous improvement by pre-filter devices, should warrant the higher rate.

The tendency is certainly toward an increase in what, for convenience, may be termed the "standard rate," and

it is therefore wise to make provision for a future greater volume of flow by designing the piping to carry the larger amount of water.

The following are the rates at some American plants:

Albany.....	3,000,000	U. S. gallons	per acre	per day
Washington.....	2,500,000	"	"	"
Pittsburgh.....	3,000,000	"	"	"
Philadelphia (Belmont)	6,000,000	"	"	"
Providence.....	2,000,000	"	"	"

By direction of the Imperial Board of Health the maximum rate of filtration was fixed in Germany at four vertical inches per hour.

The Massachusetts Board of Health finds that while such a rate is proper for new filters, a higher delivery may be assigned to those which have been in service during a long period, "owing apparently to a more extended accumulation of gelatinous films within the main body of the filtering material." *

When dealing with the question of the rate of filtration, the following table prepared by Mr. G. W. Fuller will be found convenient:

EQUIVALENTS OF VARIOUS MEASURES OF RATE OF FILTRATION

	Million U. S. Gals. per Acre per 24 Hrs.	U. S. Gals. per Sq. Foot per Hour.	Cubic ft. per Sq. Yard per Hour.	Vertical Velocity in Inches per Hour.
1 million U. S. gals. per acre per 24 hrs.	1.	.96	1.15	1.53
1 U. S. gal. per square foot per hour...	1.045	1.	1.2	1.6
1 cubic foot per square yard per hour..	.869	.83	1	1.33
1 linear inch in vertical velocity per hour.	.652	.62	.75	1

It will be observed that the rate of three million gallons per acre per day corresponds to a vertical velocity of 4.6 inches per hour.

* Rep. Mass. Board Health, 1894, p. 609.

CLEANING LONDON FILTER-BEDS.

Cleaning a filter of the slow sand type is accomplished by a gang of laborers who work upon the drained bed, and by means of sharp shovels pare off the uper half-inch of sand and pile the same into small heaps, whence it is removed to the sand-washer. This thin upper layer of sand (the *Schmutzdecke* of the Germans) contains the greater bulk of the material separated from the water by filtration. It is quite compact, and in appearance is distinctly separated from the sand below. Its imperviousness to water is what causes the filter to become "dead" and require cleaning.

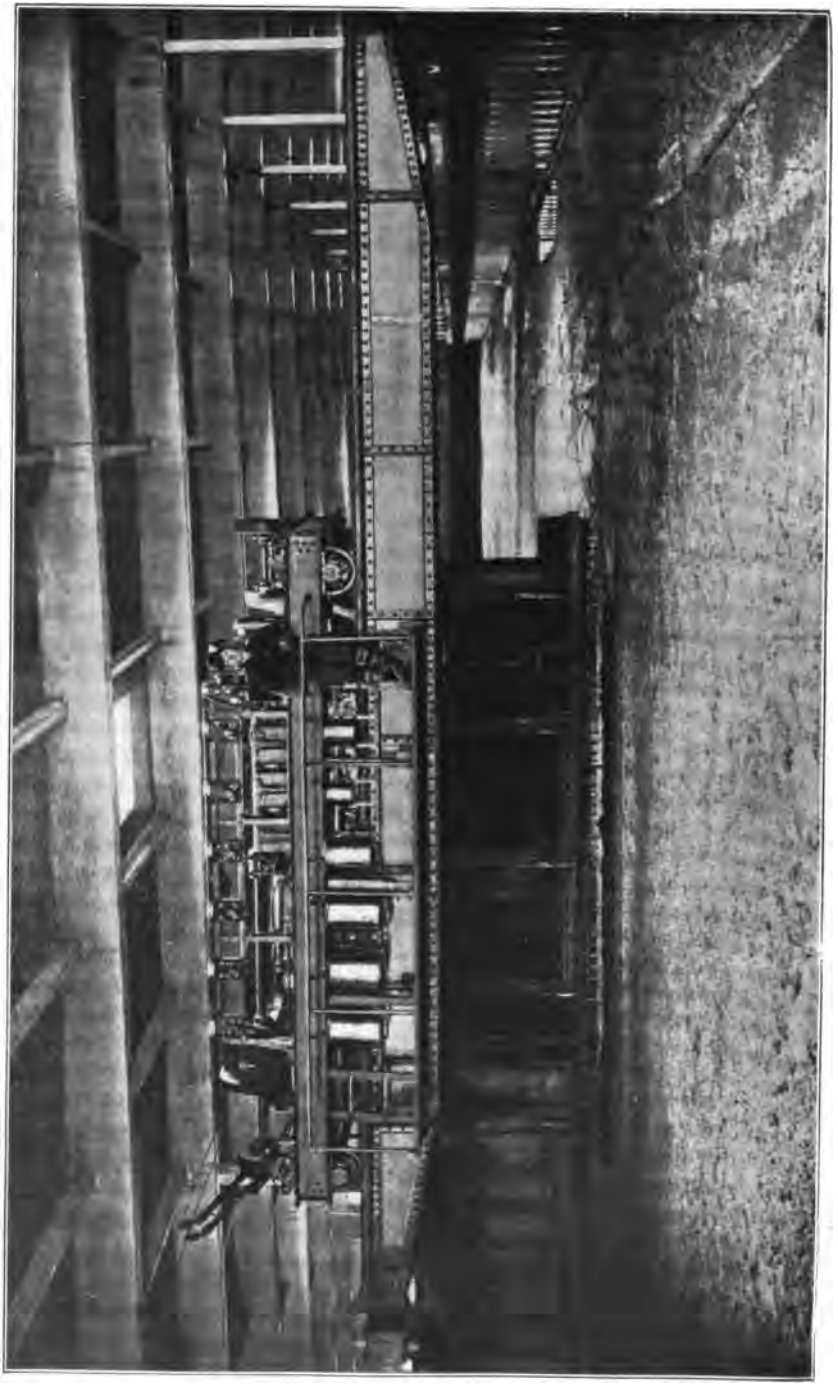
The illustration given shows the cleaning of one of the London beds before the more modern methods were adopted. The *Schmutzdecke* (a portion of which is shown in place) was scraped into piles, as now, and such piles of dirty sand were then removed to the sand-washer by the use of wheel-barrows. After washing, the barrows were again employed to return the sand to the bed.

The method of washing and handling sand is now one of greater expedition and less cost.

Water under pressure is carried in a pipe suspended from the filter roof and is delivered by hose to a hopper containing an ejector equipment. Into this hopper the dirty sand is shoveled and is carried by the stream of water issuing from the ejector nozzle into another pipe, also suspended from the roof, which delivers it to some convenient point outside of the filter. The sand may be sufficiently scoured by such treatment and ready for re-use when the water which carried it is drained away, or it may be re-washed if required.

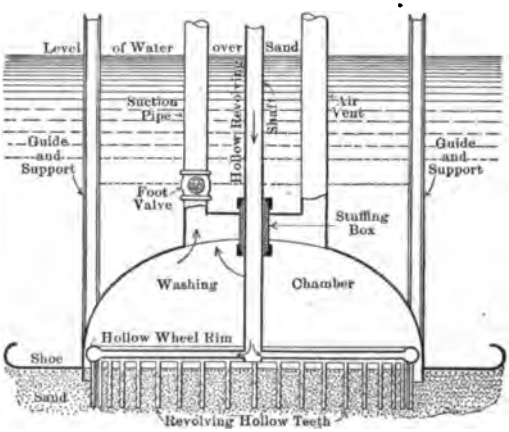
By the use of the "Nichols" washer the sand can be washed without leaving the filter. The "hopper" referred to above delivers into the Nichols apparatus, the cleaned sand is discharged directly from the machine and only the dirty wash water is carried off by the outflow pipe suspended from the ceiling. The washed sand is distributed and "surfaced" by hand.

The "Blaisdell" sand washing machine used at Baltimore



BLAISDELL FILTER-SAND WASHING MACHINE, BALTIMORE, MD.
(From Water Supply Paper No. 315.)

and elsewhere, is illustrated below and may be tersely described as possessing a washing chamber hanging from a traveling girder which spans the filter. This washing chamber may be raised and lowered so that it may be sunk unto the sand surface during use or be sufficiently elevated to clear the filter walls during transfer to another bed. Within the washing chamber is a stirring-wheel with hollow teeth, through which water under pressure enters the stirred-up sand. Suction is applied



WASHING CHAMBER OF BLAISDELL FILTER-SAND WASHING MACHINE.

"The chamber being slowly moved ahead, sliding on its shoes over the sand surface, water is forced through the hollow shaft to the hollow rim of the wheel, and thence to the hollow teeth below and through fine perforations into the sand. The dirty water from the washed sand is drawn away from the washing chamber through the suction pipe."

The above illustration of a section is from a paper by W. B. Fuller in Engineering News March 12, 1908.

to this chamber and the dirty water is thereby separated from the sand and pumped to the sewer.

As a method for prolonging the life of a filter, Hardy reports excellent results were secured at Washington, by raking the sand surface of the drained filters with iron garden-rakes. Such raking "seemed to be nearly as effective in restoring the filter capacity as a scraping; it could be done in eight hours by three laborers, and there seemed to be no ill effects from lowered efficiency." The raking was first attempted from boats, first shutting off the effluent, but "this method was not satis-

factory as the work was neither as uniform nor as thorough as necessary." *

The "Brooklyn Method" of washing a slow sand bed consists in draining off the water to within a few inches of the sand surface, opening the outlets just above this surface, setting boards on edge so as to form a channel-way about 15 feet wide and then admitting a flow of wash water at one end of such channel-way with a velocity of half a foot per second. The upper sand layer is raked during the flow until the turbidity of the wash water is materially reduced. A lengthening of the life of the filter is thus secured. Because of the hard, pasty character of the material caught in the upper sand layer of the Torresdale filters, the "Brooklyn Method" was not there successful.

The actual weight of dirt on dirty filter-sand is less than its looks would indicate. At Albany the writer found it to run about one-half of one per cent of the dirty sand dried at 110° C.

Fine dirt will slowly find its way into the lower levels of the sand bed and consequently deep cleaning will be occasionally required. At Albany the body of the sand was cleaned for the first time after the filters had been running about ten years. Since then it has been cleaned about every four years.

Excess of area, to allow normal filtration to continue while a portion of the plant is being cleaned, must be allowed for in the design. Middleton † considers that such area should run 16 to 25 per cent "of the area at work." This allowance is large even for an estimate made to suit a great variety of waters. About half of the higher figure would be more suitable. The actual allowance made must of necessity depend upon the probable frequency of cleaning, which in turn will vary with the character of water to be filtered.

It is better to design a filter of sufficient size, and construct it in a thoroughly up-to-date manner, than to expend the same sum of money for a larger but less efficient plant.

* Am. Soc. C. E., 36: 1566. † "Water Supply," p. 115.

The frequency of cleaning depends, as has been said, upon the condition of the water being filtered, and, for the same water, this condition will vary greatly with the time of year and character of the season. Thus the London beds experience difficulty from March to July; becoming during those months quickly clogged with fish-spawn, which arrests filtration, and at times renders it necessary to remove the water from the top of the filter before the obstruction can be taken off with rake and shovel.

From July until October another difficulty, scarcely less serious, is the growth of vegetation, which begins upon the bottom.

Roughly stated, it may be said that a filter becomes "dead" (i.e., nearly impervious to water), and consequently demands cleaning, once every three or four weeks in summer and about half as frequently in winter; but it is not possible to lay down hard-and-fast general rules applicable to all filters. So many variable quantities enter the consideration that the question of proper time for scraping must be answered for each filter by itself, basing decision upon intelligent observation of the rate of flow, loss of head, and the obvious general efficiency.

Where the ejector system is in use, it is not customary nor desirable to have the newly scraped filter remain out of service until the sand removed is washed and returned to its place; for the fine-sand layer should be thick enough to permit of a number of such successive scrapings without impairment of its efficiency; therefore the sand taken off during a series of parings is washed and returned at one time.

At Albany the sand-layer, which is normally 48 inches thick, has been reduced as much as 17 inches by successive parings before the original thickness was restored by replacing the cleaned sand.

The cost of cleaning a filter and washing and replacing the removed sand depends upon the plan adopted for the work, the design of the filter, and the local price of labor.

The following figures give the cost for cleaning old-style open filters by the former "hand method":

London (Southwark and Vauxhall).—To scrape and wheel dirty sand to washer requires 400 man-hours per acre of sand-surface. Labor, $9\frac{1}{2}$ cents per hour. Ice is not usually removed, but is raked into ridges. The cost of this is roughly found to be about three times that of the ordinary cleaning.

London (New River).—To scrape one acre and wheel out dirty sand requires 144 man-hours. Labor, 9.3 cents per hour.

Liverpool.—Cost of scraping and wheeling is $12.50 to $25 per acre, depending upon length of barrowing. Ice is occasionally broken up where it touches the walls, but is not removed. Labor, 9.1 cents per hour. Cost of cleaning per million U. S. gallons filtered, $1.14.

Schiedam.—Scraping and wheeling out dirty sand requires 174 man-hours per acre. Labor, 6 cents per hour. In Holland the sand is not usually washed, it being cheaper to obtain fresh sand for refilling.

Rotterdam.—The mean cost for filter management, including cleaning, washing new sand, and trouble with ice, has been during ten years, $1.35 per million U. S. gallons water filtered.

The following data for the *Albany, N. Y., filter plant* will serve for general illustration, although the plant is not the most modern one in the country. It was put in service in 1899 and was then the last word in filter construction. Originally it consisted of only the covered slow sand beds, with a sedimentation basin attached. At present a pre-filter plant using alum is interposed between the sedimentation-basin and the filters proper, and a device for chlorination of the filtrate is erected at the entrance to the clear-water reservoir.

Average dose of alum used..... 2 grains per gallon
Average dose of available chlorine used..0.49 parts per million

The slow sand beds are eight in number, with a sand area of 0.7 acre each. The composition of the bed is:

Gravel (egg size)	4	inches
" (walnut)	4	"
" (marble)	4	"
" (pea)	4	"

Sand (effective size 0.31 mm.) 40 inches (originally 48).

The pre-filters are sixteen in number, with a sand area of 820 square feet each.

The sand of the pre-filters has an effective size of 0.65 mm.

Capacity of clear-water basin, 600,000 U. S. gallons.

Dimensions of clear-water basin, 94×94 feet.

Elevation of sedimentation-basin above river, 18 feet.

Dimensions of sedimentation-basin, 382.7×600×9 feet.

Diameter of pure-water conduit to city pumping-station 48-inch (steel riveted pipe).

Depth of water on filter-bed, 4 feet.

Total cost of construction of slow sand filter-beds, including piping and laboratory, $225,000.

Cost of construction per acre net filtering area, $45,600.

Cost of sedimentation-basin, $60,000.

Cost of construction, pure-water reservoir, $9000.

Cost of land, $8290.

Cost of pure-water conduit and connections, $86,638.

Cost of engineering and contingencies, $31,000 (original).

Cost of pre-filters, $125,000.

Total cost of entire plant, $700,000.

Operation:

Average total volume of water filtered per day, 21,444,000 gallons.

Average rate of filtration per acre per day, pre-filters, 84,500,000 gallons.

Average wash water used in pre-filters, 3.6 per cent.

Average rate of filtration per acre per day, slow sand, 2,998,000 gallons.

Average depth of sand removed at each scraping, slow sand, 0.62 inch.

Average interval between scrapings, slow sand, 30 days.

Average interval between washings, pre-filters, 39.7 hours.

Average gallons per acre between scrapings, slow sand, 156,438,000.

Permissible loss of head, 4 feet.

Time required to scrape one filter, 30 man-hours.

Time required to eject sand, 10 man-hours.

Time required to level surface, 12 man-hours.

Ten volumes of water are required to wash one volume of sand.

Loss of sand by washing is five per cent.

The table on page 147, from the Bureau of Water Report for 1914, gives in detail the cost of purification by the Albany plant (quantity of water filtered, 7,817,285,000 gallons. Price of labor, $2.50 per day).

At Torresdale, Pa., the most successful sand washing was done by the use of the Nichols machine. They found that the said machine used 1200 gallons of wash water per cubic yard of sand, as compared with 2800 gallons required by the ordinary ejector method.

Hazen * considers that, as a general average, municipal filtration, excluding pumping but including all operating expenses and also including interest on cost of plant and allowance for repairs and depreciation, should cost about $10 per million gallons.

A similar estimate was made by R. Winthrop Pratt of the Ohio State Board of Health, who says: †

"It is estimated that filtered water, including interest charges and operating expenses, costs $6 to $10 per million gallons. This cost may be higher in special cases. At $10 per million gallons, the cost to each inhabitant of a city where the daily water consumption is 100 gallons per capita, would be 0.1 cent per day, or 36.5 cents per year. This means an increase in the water rate of about ten per cent. Is not this an economical way of avoiding typhoid fever and similar

* Trans. Am. Soc., C. E., 54; also see Whipple on "Value of Pure Water," page 49.

† Ohio Sanitary Bulletin, Jan., 1905.

diseases? The price of fuel used in boiling water for drinking only would be much greater than 36.5 cents per year."

COST OF FILTRATION AT ALBANY, N. Y.

Pumping Station.	Total Cost.		Cost per Million Gals.	
Engineers, firemen and oilers	$9,035.19		$1.16	
Incidental labor	791.95		.10	
Coal	12,712.03		1.63	
Oil	546.70		.07	
Repairs and supplies	3,438.86		.44	
Ice	30.53			
Total cost of pumping		$22,555.26		$3.40
FILTRATION AND STERILIZATION: *Sedimentation Basin.*				
Labor and teaming	$226.75		$0.03	
		$226.75		$0.03
Preliminary Filters.				
Attendance and clerical work	$3,230.36		$0.41	
Removing, washing and replacing sand	184.00		.02	
Repairs, supplies, etc	280.60		.04	
		$3,694.96		$0.47
Slow Sand Filters.				
Scraping beds	411.50		0.05	
Rejecting scraped sand	617.75		.08	
Washing and replacing	2,198.50		.28	
Removing ice	129.50		.02	
Reforking	81.75		.01	
Refilling beds	830.50		.11	
Watchman	729.00		.09	
Incidental labor	4,493.58		.58	
Repairs and supplies	2,113.20		.27	
Egg coal	69.75		.01	
Ice	30.53			
		$11,705.56		$1.50
Laboratory.				
Chemist	$2,100.00		$0.27	
Laboratory help	2,020.89		.26	
Supplies	567.05		.07	
Gas—86° gasoline	175.96		.02	
Egg coal	69.75		.01	
Ice	30.54			
		$4,964.19		$0.63
Hypochlorate Plant.				
Attendance	$908.60		$0.12	
Repairs and supplies	1,687.89		.21	
		$2,595.89		$0.33
Alum Plant.				
Attendance	$641.00		$0.08	
Repairs and supplies	8,032.85		1.03	
		$8,673.85		$1.11
Superintendence		2,171.94		.28
Total cost of filtration and sterilization		$34,032.34		$4.35
Total cost		$60,588.40		$7.75

Cost per million gallons filtered $\frac{\$60,588.40}{7,817,285,000} = 7.75$.

Before consenting to the large outlay of funds required for filtration by the English filter-bed system, the taxpayer very properly asks *what efficiency may be looked for* from such a construction.

The best answer to this question is to quote the recorded duties of some existing plants. (Results in parts per million.)

	Color.	Turbidity.	Bacteria per cc.
Albany, N. Y., 1914 (raw).....	33	36	66,850
Albany, N. Y., 1914 (filtered)....	22	1	29
Providence, R. I., 1913 (raw)....	46	.....	1,500
Providence, R. I., 1913 (filtered).	32	.....	10
Torresdale, Phila., 1914 (raw)....	15	20.2	16,800
Torresdale, Phila, 1914 (filtered) .	10	0.6	246
Washington, 1915 (raw).....	0	190	4750 (average)
Washington, 1915 (filtered).....	0	0	12 (average)
Pittsburgh, 1916 (raw).....		100 and over	150 to 150,000
Pittsburgh, 1916 (filtered).....	60% removal	0 to 1	Seldom over 10

When the Albany filters were first placed in service their record was:

Sept. 1899, Bacteria in raw water..... 16,800 per c.c.
" " " filtered water..... 343 per c.c.
" " removed..... 97.6%
Sept. 1900. Bacteria in raw water..... 5000 per c.c.
" " " filtered water..... 24 per c.c.
" " removed..... 99.4%

It is worthy of notice that the efficiency of the beds increased after the first few months of use. In other words, a new filter cannot be expected to render such good service as one which has become "ripened."

The effect of water improvement by filtration upon the typhoid death-rate in New York State is well shown by the following data secured from the Health Department report.

Average annual typhoid death-rate per 100,000 population in seven cities of New York before introduction of water-improvement (slow-sand filtration)..... 46.5
Average typhoid death-rate for 1915 in same cities..... 13.3
Similar data for eleven cities of the state before improvement by mechanical filtration..... 56.2
Same for eleven cities for 1915..... 14.4

No better illustration can be given of what sand-filtration is capable of accomplishing than is presented by the record of the ten filters at Altona, Germany, during the month of February, 1893. The average number of bacteria per cubic centimetre in the raw Elbe water for that month was 28,667, whilst the corresponding average for the filtered water was only 90; showing a removal, by filtration, of 99.69 per cent of germs of all kinds.

What this removal meant for the city of Altona during the cholera outbreak at Hamburg in 1892 has already been touched upon (page 49), and may be epitomized in a single word—"safety."

A similar illustration is to be found in the data from Cherbourg, France. At the time of the epidemic of 1898–99 the city proper, of a population of 32,494, derived its supply from the river Divette, with imperfect purification by an old-type filter. At the same time the garrison numbering 8239, was supplied with water from the same source but without filtration.

The typhoid death-rates were:

Civil	109 per 100,000
Military	1893 per 100,000

A second epidemic occurred in 1908–09.

At that time the garrison supply was as before, but the city carefully filtered its supply by the Puech-Chabal system (the intake being as in the past).

The typhoid death-rates were:

Civil	6.5 per 100,000
Military	1594.0 per 100,000

There was one barrack within the city and no deaths occurred therein.

Col. A. M. Miller, U.S.A., was the first to lay particular stress upon the necessity for a low number of bacteria per cubic centimetre yet remaining in the water after filtration, as

together with a high percentage of removal, as properly representing a filter's efficiency.

This seems a just view, for a high percentage of removal might yet permit of an entirely undesirable number of bacteria in the filtrate when operating upon a raw water of high pollution.

Given a raw water containing a large number of bacteria per cubic centimetre, it is a relatively easy matter to show a high percentage of efficiency in a filter used to purify the same; while on the other hand it is difficult to secure a high percentage of germ removal, even with the best of management, if the "count" on the raw water be very low.

A low residual number of bacteria should be required, rather than a high percentage of removal, and it is also right to demand the absence or practical absence of the *Bacillus coli communis*.

If the *Bacillus coli communis* be absent in a filtered water, it is safe to assume the absence of the *Bacillus typhosus* also. The occasional presence of a few of the former is not greatly objectionable, for the reasons that it is much more numerous in even an infected raw water than is the *Bacillus typhosus;* it has a greater longevity under adverse conditions such as are furnished by water-carriage; and, further, it has been experimentally shown that, of the two forms, the *Bacillus typhosus* is the more readily removable by filtration; * not because of material difference in size, but rather on account of its relatively small power to resist the adverse conditions present in the filter.

The thoroughness with which nitrification, and consequent purification, can be accomplished, by filtration through shallow beds of even very coarse material, has been worked out and demonstrated by the investigations of the Massachusetts experiment station, and one important point elucidated is that a small amount of oxygen (1 to 3 per cent) in the air of the filter is as effective as a larger quantity.

The following extract from a report made some years ago

* See Report Mass. State Board of Health, 1898, p. 487.

by Mr. G. W. Fuller, then in charge of certain experimental work at the station, will give an idea of the efficiency with which bacteria may be removed by five feet of filtering material intelligently managed:

"The actual efficiency of the filters was tested by the application of typhoid-fever germs and other important kinds of bacteria, and observations on their passage through the filters. The pure cultures of the micro-organisms were grown in dilute bouillon solutions. Twenty-five or fifty cubic centimeters of these solutions, containing millions of germs, were applied to the filters in a small quantity of water, and the effluent was examined at frequent intervals for several days. Fifty-five such experiments were made during the first five months of 1892, with these average results:

Number of filters tested	11
Number of experiments with typhoid-fever germs	22
Number of experiments with *B. prodigiosus*	19
Number of experiments with *B. coli communis*	14
Average rate of filtration, gallons per acre, daily	1,350,000
Number of bacterial determinations	914
Average number of bacteria per cubic centimetre applied	104,200
Per cent removed	99.48

[The extreme limits in the rates of filtration in the several experiments were 280,000 and 2,600,000 gallons per acre, daily.]

"These experiments were very severe tests upon the efficiency of the filters in removing bacteria, because the number applied was probably greater than would occur in practice, and furthermore the organic matter introduced with the bacteria served them as a food material. The experiments made during the latter portion of the year are much fairer, because the bacteria were applied in small and long-continued doses at frequent intervals, and the food material applied with them did not increase the organic matter in the river-water beyond the limits of variation observed from time to time in the amount originally present. The species of bacteria used was *B. pro-*

digiosus, on account of its easy and reliable differentiation, its similarity to the typhoid-fever germ in its mode of life in Merrimac River water, and the fact that it has never been found native in this country. In the following table are summarized the average results of daily experiments from September 16 to December 31, 1892:

Number of filters experimented upon	11
Number of bacterial determinations	2,372
Rate of filtration, gallons per acre, daily	1,700,000
Average number of *B. prodigiosus* per cubic centimetre applied	5,700
Per cent removed	99.87

The necessity for *filtering to waste* for a time after cleaning a slow-sand filter, as indicated by the earlier Altona results, does not accord with the experimental experience obtained at the Lawrence experiment station,* nor can it be classed as sound modern practice. If the scraped bed be carefully filled to above the sand-surface with clean water admitted through the underdrains, and filtration be then resumed at a moderate rate, which is gradually increased to the normal flow, there is no reason for obtaining any other than good results. The necessitate for wasting the filtrate after ordinary scraping has not been felt at Albany.

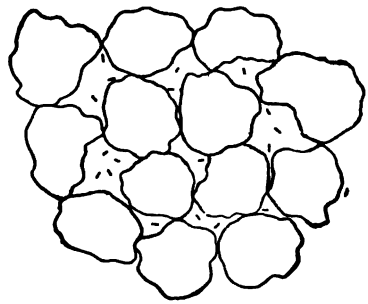
It is proper to require a slow and careful filling of the sand-voids with the water admitted through the underdrains, for if such water be passed in hurriedly, disturbance of the sand body by the escaping air will take place, resulting in the passing of bacteria through the channelways so formed.

Especial care should be taken that no *freezing of the sand* take place during the time of cleaning. The difficulty of preventing this is, of course, a question involving climate, and for very cold countries the only solution of the problem is the construction of covered filters.

* Report Mass. State Board of Health, 1893.

Where open filters are in use in Europe, the attendants depend upon a careful watching of the weather, and very rapid work during cleaning, to prevent freezing. Should the sand once become frozen, the difficulty is a serious one, for, as was demonstrated at Altona, the water above the sand does not thaw the ice nearly as rapidly as one would expect, and moreover, thawing takes place unequally over the surface, whereby a discharge of the whole filtrate occurs through only a fraction of the bed, with most unsatisfactory results.

A recent critic of the filter-bed system refers to the removal, by the bed, of ninety-odd per cent of all bacteria present in



SKETCH SUGGESTING RELATIVE SIZES OF BACTERIA AND SPACES BETWEEN SAND GRAINS.

the raw London water, and then notes that reduction of the typhoid death-rate has been by no means in so large a proportion. As an explanation of the observed facts, he suggests that the small size of the typhoid bacillus prevents its being arrested by the filter as easily as its larger companions.

In reply it must be said, firstly: Typhoid fever would not entirely disappear from London, or any other city, were the water-supply absolutely sterile, for the sufficient reason that bad water, although a main cause of the disease, is not the only one. Secondly: Filtration is very far from being a simple straining process; were it so, all bacteria would pass the filter with equal facility, for differences between the several sizes of these extremely minute objects would be small indeed as

compared with the spaces between the grains of sand. Whatever its size, the bacterium is caught by the zoogloea jelly surrounding the grains of sand, or is killed by the adverse conditions set up during nitrification, or both.

It is worthy of note that the Massachusetts Board of Health * found that if highly polluted water be filtered and the filtrate be then passed through a second filter, the efficiency of such second filter will be low and remain low for a long time, owing to the lack of the gelatinous coating on the sand grains.

The character of sand most suitable for water-filtration now receives decidedly more attention than it did in the past, for it is recognized that not only must a proper size of grain be secured, but that the degree of uniformity in size must be considered as well An ideal sand would be one having all of its grains exactly of one size, therefore it is sought to have the "uniformity coefficient" as near unity as possible.

Moreover, it is to be remembered that much carbonate of lime present in the sand will harden the water filtered through it.

It is easy to determine the presence of carbonate of lime, by observing whether or not the addition of hydrochloric acid to the sand causes an effervescence, but an accurate knowledge of the amount of the carbonate present calls for a chemical analysis.

A large amount of work has been done at the Lawrence experiment station (notably by Hazen) upon the efficiency of sand,† and the expressions there employed are now widely adopted.

The "*effective size*" of a sand is that diameter of grain than which ten per cent of the sand, by weight, is either equal to or less. It is expressed in millimetres.

If there should be also determined that diameter of grain than which sixty per cent of the sand, by weight, is either equal to or less, and if this value be divided by the "effective

* Report of 1896, p. 524.

† See Reports of Mass. State Board of Health, 1892, p. 541, and 1894, p. 703.

size" already found, the quotient will be the "*uniformity coefficient.*"

The mechanical analysis of sands is most easily accomplished by the use of standardized sieves. Those used by the writer are of brass of the following sizes and are "nested":

No. of Mesh.	True Size in Millimetres.
100	0.16
80	0.19
60	0.27
40	0.46
20	0.88
16	1.16
10	2.04
8	2.74

It is possible to purchase sieves of the larger sizes accurately made by boring plate metal with standard drills; but the smaller sizes must be woven, and therefore have to be standardized. This is best done by the method described in the Massachusetts State Board of Health report for 1892.

For each sieve a definite number of those sand grains are taken which are the last to pass, and which consequently most nearly correspond in diameter with the mesh of the sieve. After counting, these grains are weighed in milligrams, and their total weight divided by their number will give the weight of one. The specific gravity is easily taken by the bottle method.

Now, since the volume of a sphere is equal to $\frac{1}{6}\pi d^3$, and also since $W = V \times$ specific gravity, we have

$$\frac{1}{6}\pi d^3 = \frac{W}{\text{Sp. Gr.}},$$

in which d, the diameter of a sphere equal in bulk to the sand grain, is the only unknown quantity.

Thus the true size of each mesh is secured and recorded.

The mechanical analysis of sand is accomplished as follows: Take 100 grammes of the sample. Place this in the top of the "nest" of sieves, thoroughly shake and weigh the

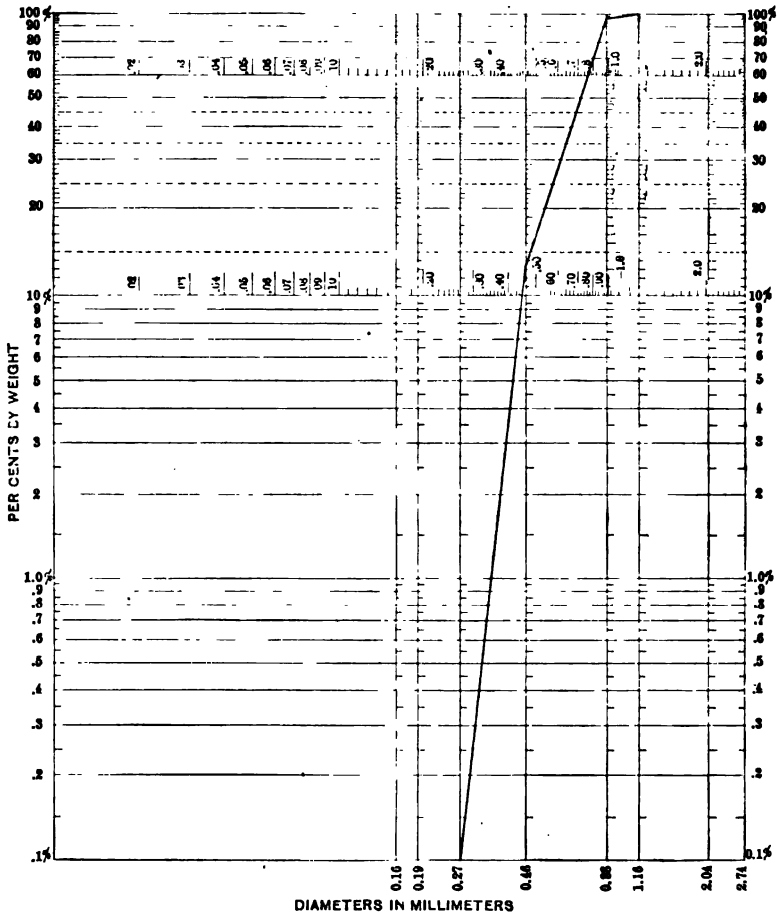


DIAGRAM OF MECHANICAL ANALYSIS OF SAND.

material passing each sieve. Convert these weights into percentages of the original weight taken and plot them as illustrated above. The data for the curve there given are as follows:

Size of Sieve in Millimetres.	Per Cent of Sand Passing.
0.16	0.0
0.19	0.0
0.27	0.1
0.46	13.5
0.88	96.0
1.16	99.4
2.04	99.6
2.74	100.0

It will be observed that the curve cuts the ten per cent line at .45 and the sixty per cent line at .76. Hence the "effective size" of the sand under examination is .45 and the "uniformity coefficient" $.76 \div .45 = 1.6$.

Data as determined by Mr. H. W. Clark for sand from some foreign filters are here given:

	Effective size.	Uniformity coefficient.
Hamburg	0.31	2.3
Altona	0.37	2.0
Berlin	0.35	1.7
Zurich	0.28	3.2
Liverpool	0.32	2.5

Other data are:

Washington	0.32	1.64
Albany	0.31	2.3
Pittsburg	0.29	2.1
Philadelphia	.28 to .36	2.5

A good general specification for sand would be:

Effective size, 0.35 m.m. (about);
Uniformity coefficient, 1.5 m.m. (about).

In an article on the New Haven plant Mr. C. A. Ferry says: *

"Our specifications for sand were: Material which will pass a screen with 0.1-in. mesh and will not contain more than

* Eng. News, May 9, 1907.

0.5 per cent of material which will pass a screen with 0.01-in. mesh. It shall have an effective size of not less than 0.25 m.m. nor more than 0.35 m.m.; and shall have a coefficient of uniformity of nor more than $2\frac{1}{2}$."

"RAPID" OR "MECHANICAL" FILTRATION

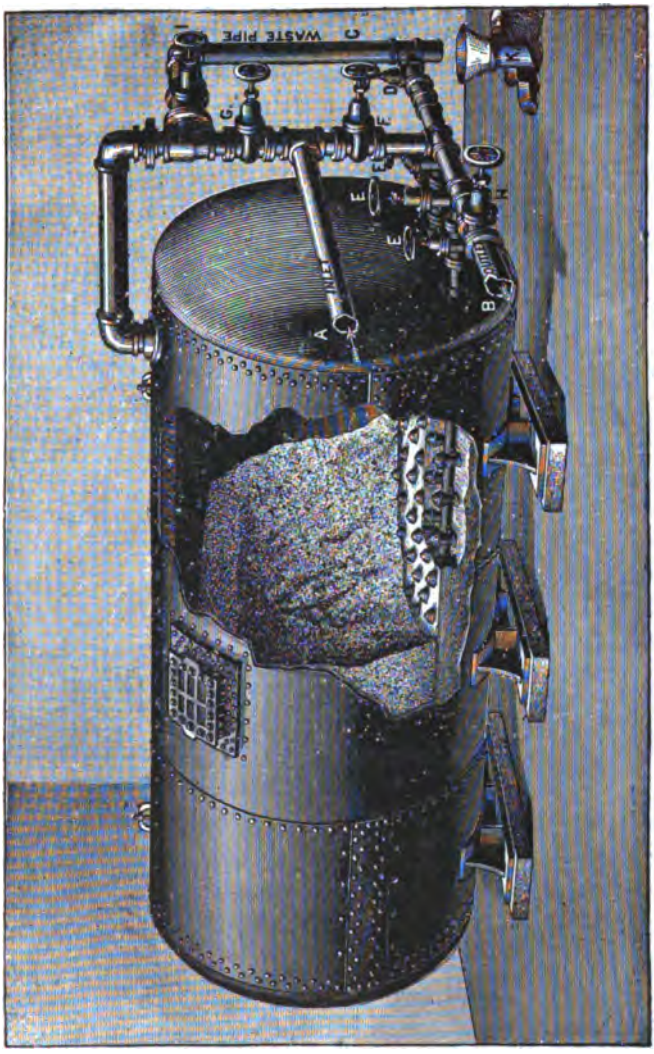
Roughly outlined, this system consists in adding to the water to be filtered a minute dose of some "coagulating" material, usually common alum, or better, aluminum sulphate, averaging about one grain per gallon, and then after a short sedimentation period, admitting the water to the filter, which is a tank of wood, iron, or concrete, containing a filtering bed consisting of about 27 inches of sand (.40 to .65 m.m. effective size) resting upon about 9 inches of gravel. Above the sand surface the water stands about 24 inches deep. The alkalinity naturally present in the water decomposes the alum, with the formation of a white flocculent precipitate of aluminum hydroxide, quite jelly-like in appearance. For instance, the carbonate of calcium, representing the alkalinity, acts as follows:

$$Al_2(SO_4)_3 + 3CaCO_3 + 3H_2O = 2Al(OH)_3 + 3CaSO_4 + 3CO_2.$$

The action of this aluminum hydroxide is much the same as that of the white of egg in clearing coffee. It entangles all suspended matter, bacteria as well as inorganic material, and deposits the same on the surface of the sand, whence it is removed and driven into the waste-pipe by a reverse current of filtered water at the time of cleaning the filter. Thus, it will be observed, the mechanical filter produces an artificial inorganic jelly to replace the "bacterial jelly" of the slow sand filter-bed, already alluded to on page 119.

A further action of the precipitated aluminum hydroxide is to unite with the soluble coloring matter of the water, whereby the filtrate is rendered colorless. The proper "dose" of alum solution is administered by means of some small automatic measuring apparatus exterior to the filter; the liquid flowing

thereto from the dissolving tank, where the water solution of the coagulant is prepared of convenient strength.



AUTOMATIC PRESSURE-FILTER.

For small establishments it is a convenience to make use of a "closed" or "pressure" filter similar to that illustrated on this page, for the reason that it can be placed directly upon

the service-main, thus allowing no interruption in the line of the supply. It is not easy, however, to carefully watch such a filter, and it is open to sundry other objections, notably a lack of uniformity in action. For purposes of public service there is some prejudice to its use as a substitute for the open or "gravity" type.

On pages 161 and 170 are given illustrations of such "open" or "gravity" mechanical filters of the tub form, still in use for municipal service, but commonly replaced in larger plants by rectangular concrete tanks such as shown on page 168. "Units" are erected in numbers and sizes suited to the quantity of water to be filtered.

The rate at which water is passed through these filters is very great when compared with what is furnished by the English filter-beds already considered. One hundred and twenty-five million gallons per acre per twenty-four hours may be taken as a fair index of what is to be expected of them.

It has been already said that alum is used in their operation. The necessity for the use of this or some other coagulant is imperative and should be impressed upon the mind, for, however well the straining action of the sand-bed may clarify the water, the great rapidity of flow precludes the proper removal of bacteria without they be entangled in the alumina jelly noticed above.

Alum * is the principal, but by no means the only "coagulant" that is used in mechanical filters. Salts of iron were suggested some years ago as a cheap substitute for alum and are so employed, especially in the Middle West, but their use is not greatly extended.

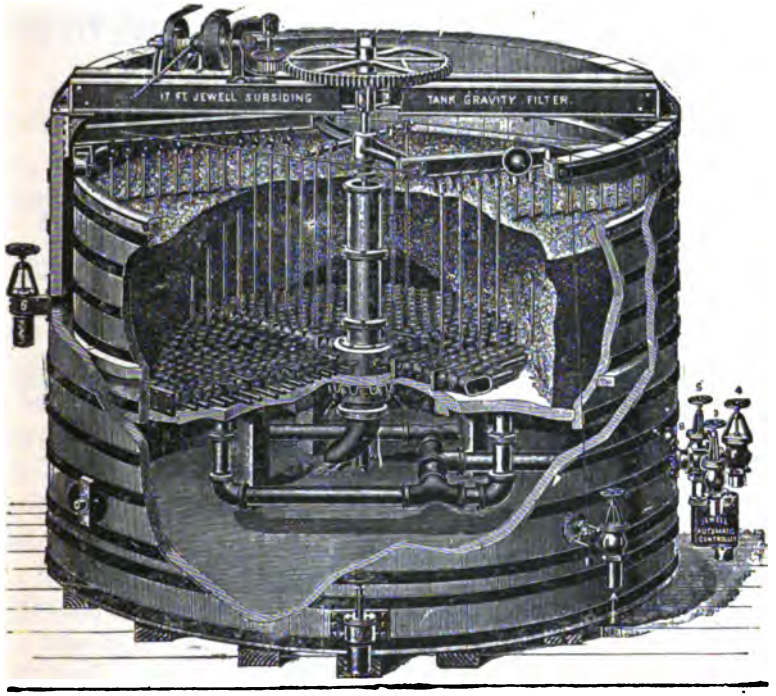
Large plants using ferrous sulphate and lime are in successful operation, notably at Cincinnati and New Orleans.

The ferrous sulphate is employed to replace the alum, but as it is not quickly acted upon by the natural alkalinity of the water (as is the case with alum), the addition of lime

* Used henceforth to denote basic aluminum sulphate.

is required to cause the rapid formation of the hydroxide of iron.

At Loraine, Ohio, scrap iron was used. Sulphurous acid, formed by burning sulphur and admitting the fumes mixed with steam to a condensing-chamber, was allowed to act upon the iron scrap in a revolving drum. The iron sulphite formed



"OPEN" OR "GRAVITY" MECHANICAL FILTER, SHOWING SEDIMENTATION-CHAMBER BELOW SAND-BED.

was subsequently decomposed with lime, and the resulting iron hydroxide acted as a coagulant in a manner entirely similar to the corresponding compound of aluminum.

The advantage claimed for the iron process is economy in cost of coagulant, and rapid settlement of the flock, but the expense of application is increased, which partly offsets the lower first cost, and moreover, the method does not work well in some instances. Iron salts will react with the organic color-

ing matters in certain peaty waters with the formation of soluble compounds that increase the color of the filtrate.

As already stated, the municipal plant of Cincinnati, Ohio, filters the Ohio River water by use of the iron and lime process and the results are certainly successful. The following data for that plant are for 1913:

Capacity, 112 million gallons daily.

Dose of iron sulphate 1.6 grains per gallon (costing $12 per ton).

Dose of lime, 0.81 grains per gallon (costing $5.69 per ton).

Dose of chlorine (liquid) .12 parts per million.

Filters have 30 inches of sand, 0.32 m.m. effective size, resting on V-shaped under-drains 8 inches deep and filled with gravel ½ to 1 inch size.

Raw water is pumped to settling-basins, whence it flows to the filters, developing electric power by its fall.

Time of settling in such basins, about forty-eight hours.

Coagulation period averages nine hours. It is never less than 4½ hours.

Average time between washings, 17¼ hours.

Average time to wash a filter, 4.15 minutes.

Average wash-water used, 2.65%.

Average bacteria per c.c. in raw water, 16,100.

Average bacteria per c.c. in filtered water, 56.

Average bacterial efficiency, 99.7%.

Cost per million gallons water delivered, $3.92.

Of this $1.67 was for chemicals.

Based on the figures given by J. W. Ellms, the above figure for cost of chemicals would increase to about $3.05 if alum were used.

At New Orleans in 1910 the record stood:

Lime, 4.8 grains per gallon.

Ferrous sulphate, 0.76 grain per gallon.

Average period between washings, 136.6 hours.

Wash-water required, 0.75 per cent.

Rate of filtration, 59.9 million gallons per acre per day.

Cost per million gallons:

Chemicals, supervision, and labor	$6.60
Wash-water and reservoir cleaning	0.17
	$6.77

The plant is of peculiar type and not strictly comparable with mechanical plants generally.*

The plant at Cohoes, N. Y., is a small one of only eight million gallons capacity, but it is modern and will serve as a good illustration of an alum-using filter. The water is pumped from the Mohawk River to a sedimentation reservoir, whence it flows to the plant, receives its dose of alum on entering, passes to the "coagulation" or "reaction" basin and then on to the filter house. Chlorination is accomplished by the use of "bleaching powder" (so-called "hypochlorite of lime") which is added to the water after it has passed the filters. The filters are eight in number, each of one million gallons capacity. The filter-beds consist of 27 inches sand, resting on 4 inches $\frac{1}{4}$-inch gravel, three inches $\frac{1}{2}$-inch gravel, and two inches $\frac{3}{4}$-inch gravel. The water above the sand is 24 inches deep.

The dose of alum is about one grain per gallon usually, although at times rises to twice that quantity.

The dose of bleach is 0.3 part per million of available chlorine.

Cost of alum, $1.05 per hundred pounds.

Cost of bleach, $1.95 per hundred pounds.

Time between washings, twelve hours.

Coagulation period, two to four hours.

Bacteria in raw water, 20,000, 1912.

Bacteria in filtered water, 5, 1912.

What amount of coagulant should be used is a question best answered by the attendant in charge; for not only will

* See Engr. Record, 64: 356.

the proper "dose" vary with different plants, but even in the same plant it may differ from day to day, and certainly will change from season to season. One grain per gallon is a fair estimate for a rough one. This amount may be often somewhat lessened with satisfactory result, but also must frequently be materially increased.

It should be remembered that good results are what are looked for, and that if they be not obtained by the dose of coagulant adopted, such dose must be gradually increased until the maximum amount allowable shall have been reached.

It is true, as may be seen from the equation already given, that the use of alum increases the permanent hardness of the water because of the formation of calcium sulphate; but the extent of the hardening is commonly insignificant, as an objection, compared with the outlay caused by heavy doses of the coagulant.

The influence of turbidity upon the quantity of alum required is an interesting matter worked out by Fuller in connection with the Louisville experiments. It seems that marked turbidity calls for a dose of coagulant entirely beyond what the soluble salts present in the water demand; and that if the additional dose fall short of what is required by the "absorptive power" of the suspended matter, coagulation fails and the chemical is practically wasted. In view of this, Fuller dwells upon the economic value of sedimentation as a preliminary to filtration of very turbid water; * the good point is further made that when the water (Ohio River) is muddy, and consequently requires an extra amount of coagulant, with its attending increase of boiler-incrusting salts, the raw water is then so low in such substances as produce hard scale that the total incrusting power of the filtrate is less than that of the raw water when at its clear stage.†

It is worth remembering that theoretically a "dose" of one grain per gallon of aluminum sulphate (containing 17 per

* Louisville Report, p. 386.
† *Ibid.*, 248.

cent Al_2O_3) will require about $7\frac{1}{2}$ parts per million of "alkalinity" in the water for its complete decomposition.

The chemicals required for mechanical filtration are usually prepared in strong solution, or suspension, in suitable tanks and are supplied thereform in liquid form to the raw water. "*Dry-feed*" is, however, employed occasionally, the chemical in solid form and known weight being added to a tank through which water is flowing in an upward direction on its way to the main raw supply.

In plants using lime, or "bleach," large doses of the chem-

CONSOLIDATION OF FILTER-BED, COHOES.

ical may readily form hard deposits in the bed, especially in cold weather when carbon dioxide is high in the water. A mass of "conglomerate," due to this cause, and consisting of underdrain gravel cemented together by calcium carbonate formed in the bottom of one of the Cohoes filters during the winter of 1915.

It is common to write specifications demanding that "Filter Alum" shall contain not less than 17.5 per cent of Al_2O_3.

Whipple and Longley * have shown that a basic alum

* J. Infectious Diseases, Sup. 2, Feb., 1906.

(i.e., one containing an excess of Al_2O_3, as is commonly the case if that item be over 17.5 per cent) will produce a more rapidly forming and better flock than will be given by a normal alum.

C. P. Hoover, Chemist to the Columbus, Ohio, Filter Plant, in October, 1915, patented a process for supplying "filter alum" at greatly reduced cost by simply boiling bauxite in sulphuric acid, in proportions suitable for the formation of a basic aluminum sulphate; adding water until the dilution is equivalent to the alum "feed" commonly used and then, without filtration, employing the solution with its contained "chemical mud" for addition to the raw water in the usual way. Not only is there a saving of "five distinct steps in alum making, namely, filtering, concentrating, crystallizing, grinding, and redissolving," but the "mud" itself is claimed to possess the advantage of furnishing nuclei for starting coagulation.

Considerable discussion has arisen concerning the *arsenic content of filter alum*,* the arsenic being derived from the arsenical pyrites from which the sulphuric acid used in the manufacture of the alum was made. The amount of the arsenic present is, however, altogether too minute to be of moment. Thus, as Bartow and Bennett have shown, assuming the water to have received the large dose of six grains of alum per gallon, and assuming that all of the arsenic remained in solution in the filtrate, which is a practical impossibility, then "since arsenic is not a cumulative poison, a person must drink 1285 gallons of the filtered water at one time to obtain a minimum medicinal dose of arsenic."

Danger to health from the use of alum is a topic fruitful of discussion among the many who are not posted as to its manner of action; but those who are better informed know that free alum never reaches the filtrate in a well-ordered plant.

Alum in the filtrate means a useless waste of material, not to be excused. Reference to the equation already given shows that in order to produce the aluminum hydroxide jelly, upon

* J. Am. Water Works Asso., 2: 585.

which successful filtration depends, the alum admitted to the water must be entirely decomposed, and never reaches the water consumer.

MECHANICAL FILTER PLANT, NORFOLK, VA.

The method of testing for free alum is very simple, and the filter attendant, constantly on watch for it in the filtrate, should so manage the "dose" employed as never to allow it to pass beyond the sand-bed.

The illustration on page 167 gives an idea of how a collection of the filtering units of the tub form is set up.

That given below shows the inside of the filter-house connected

MECHANICAL FILTER PLANT, ERIE, PA.

with a group of rectangular concrete filter-tanks at Erie, Pa., a form commonly built for large works. It will be observed that only the ends of the filter tanks extend into the house, the remainder of them being covered by the outside terrace.

Washing filters of the type illustrated on pages 161 and 167 is assisted by revolving rakes, driven by power. A reverse current of clean water, entering through the bottom valves, loosens up the entire depth of sand and causes the wash-water, with its contained dirt, to overflow the rim of the drainage gutter and thence passes to the sewer.

The amount of wash-water used for purposes of such cleaning is an item for consideration, for it is, of course, lost to the regular volume of filtered supply.

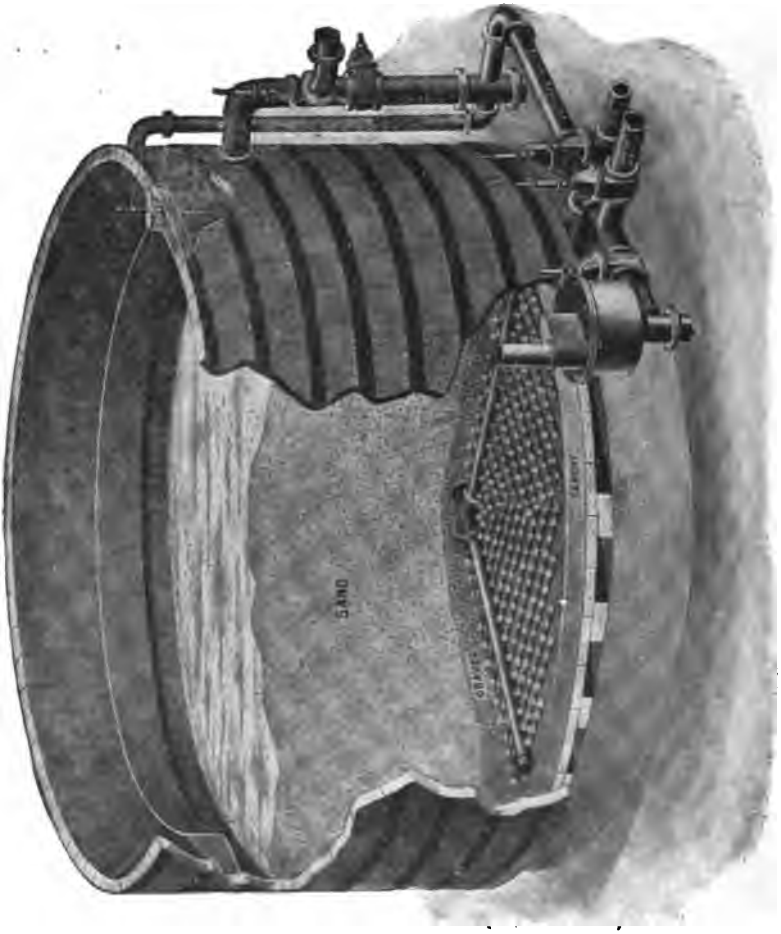
The quantities used at sundry plants must naturally vary with local conditions, but a fair general statement will place it at from 2 to 3 per cent of the total water filtered.

In plants of the types pictured on pages 168, 170 and 171, stirring rakes are omitted and the required scouring of the sand is secured by driving air up through the sand-bed at a pressure of about five pounds per square inch. This "air wash" is continued for about three minutes, after which the wash-water is driven up through the under-drains as usual, for a period of about four minutes, and the dirty water escapes through gutters leading to the sewer. The entire length of time during which the filter is out of commission due to the operation of washing is thus only a question of a few minutes. It is not desirable to make a thorough removal of all dirt by the washing process for the reason that a portion of the "catch" of the previous run forms a sort of thin *Schmutzdecke* as it falls back upon the sand-surface at the end of the wash and thereby increases the efficiency of the filter.

It is more common than not to have the compressed air used for the "air-wash" driven through the same valves in the under-drain system that are used to carry off the filtered water; but in some designs there are special valves used for the passage of air alone. This arrangement is somewhat more expensive as to first cost.

Mr. J. W. Ellms has shown that the "air-wash" and mechanical stirrers may be dispensed with in cleaning, provided that the upward flow of wash-water can be increased in velocity

to eighteen inches per minute as measured above the sand-surface. Mr. W. Wheeler patented a form of bottom and under-



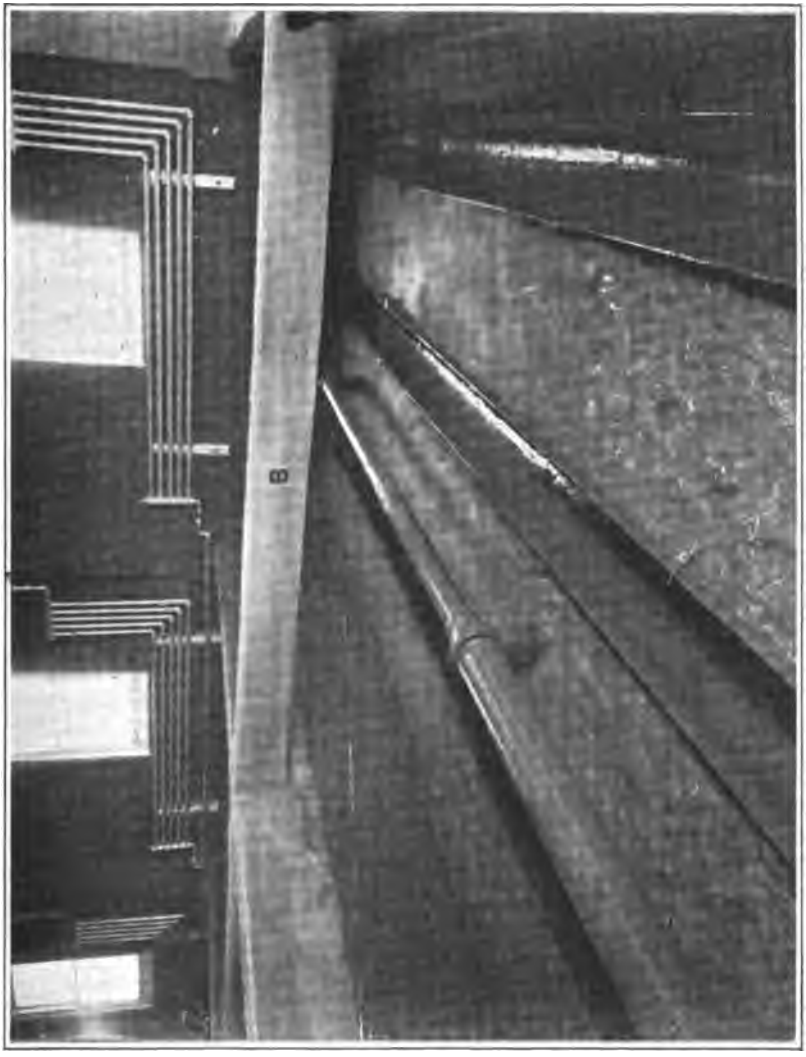
CONTINENTAL AIR WASH GRAVITY FILTER.

drains designed to allow of increased velocity of wash-water and of its uniform distribution.* This is illustrated on page 172.

After receiving its dose of alum, but before the filter-sand

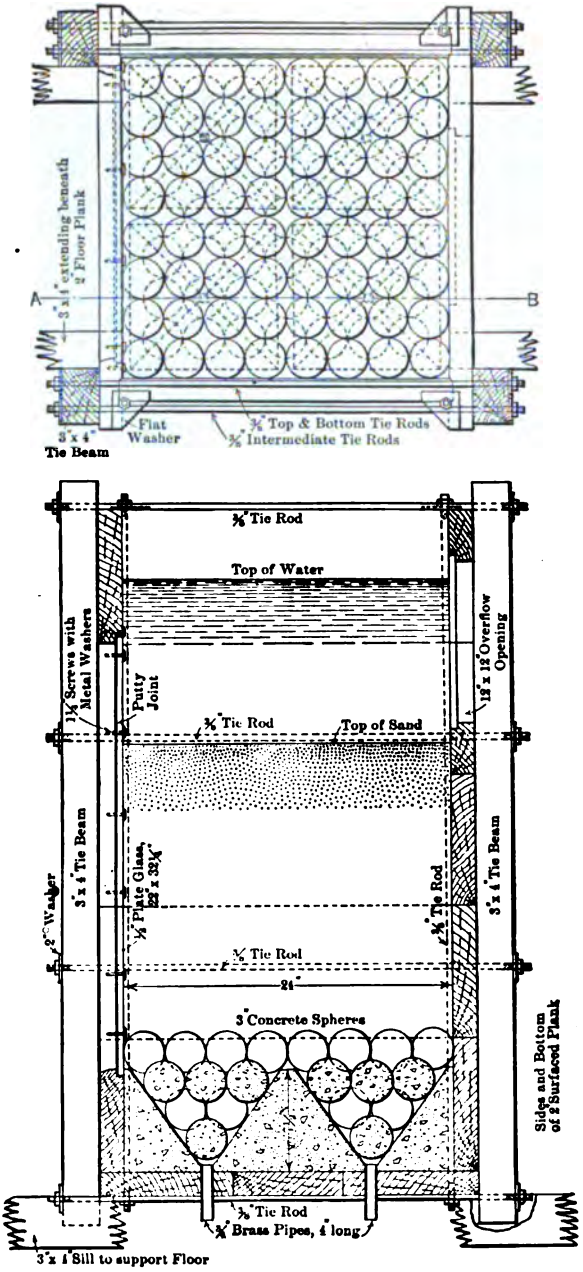
* See also paper by R. S. Weston, Eng. News, July 2, 1914.

is reached, the water passes through a "coagulation" or "reaction" chamber, depending in size and shape upon the design



PORTSMOUTH, OHIO, FILTER PLANT.
(Showing "air-wash" in operation)

of the plant, wherein opportunity is given for sedimentation of a portion of the heavy magma produced by coagulation; otherwise the sand-bed quickly chokes and the labor and expense of cleaning are greatly increased.



VERTICAL SECTION A-B

THE WHEELER FILTER BOTTOM.

As is seen from the sectional cut on page 161 a chamber is provided in some filters of the mechanical type whereby sedimentation advantages are to an extent secured even when the water is in rapid motion.

For the information of those unacquainted with this type of mechanical filter, let it be said that each "unit" (of which there are eighteen in the battery at Elmira) consists of a tub-shaped vessel about 14 feet high, and open at the top.

The bed of filtering sand, 3 feet 6 inches deep, together with the washing machinery, occupy the upper portion of the tank, leaving below an empty chamber 6 feet high, through which the raw water must pass on its way towards the sand.

A test was made to determine what this lower chamber would do in the way of relieving the filter proper of a portion of its work. The water, carrying its dose of alum, entered in a tangential direction, near the circumference of the circular bottom, and flowed to the sand-bed through a pipe in the centre of the roof.

Such an arrangement naturally caused the water to take up a movement of rotation, more or less coincident with the surface of a cone whose base was the floor of the chamber and whose apex was the orifice in the roof.

Upon opening the chamber at the end of a seven days' run, a large quantity of aluminum hydroxide was found lying upon the floor in forms like drifted snow and varying in depth from almost nothing near the circumference to 14 inches and more towards the centre of the bottom. Its volume was equivalent to many cubic feet. The best idea of the amount of deposit and of its appearance is given by the accompanying flashlight photograph (see page 174), which also shows the uprights, graduated to inches, standing therein.

The photograph shows but poorly one other feature of this aluminum hydroxide deposit, which was of considerable interest, namely, the numerous ball-like aggregations occurring throughout the mass. It would seem that the hydroxide had in many places been rolled together and built up much after the same manner that a boy accomplishes the gradual enlarge-

ment of a ball of snow. This formation resulted from the rotary motion given the water by the special device for its introduction already alluded to. Such a motion is favorable

DEPOSIT OF 'COAGULATED" MATERIAL IN SETTLING-TANK OF MECHANICAL FILTER. ELMIRA PLANT.

to the formation of large flocks in a liquid in which aluminum hydroxide is already formed. Certainly it is a mistake to suppose, as has been so often maintained, that the most rapid "coagulation" and precipitation of the hydroxide is neces-

sarily to be secured by permitting the liquid containing it to remain in a state of complete rest. The photographs (on page 176) illustrate that gentle rotary motion, far from being objectionable, is a distinct advantage. The two jars there shown differ from each other but in the fact that the left-hand one had its contents gently rotated, while the contents of the companion was maintained at complete rest In each the same quantity of hydroxide had previously been formed. The photograph indicates how progressively advantageous was the rotary motion for the formation and deposit of large flocks of the hydroxide; nor is this to be wondered at when one considers that the movement in question furnished opportunity for more frequent collision, with resulting cohesion, of the growing flocks.

With reference to the bacterial efficiency of these tanks, it was interesting to observe that at Elmira an average of 42.6 per cent of the bacteria present in the raw water had been removed by the time the sand was reached.

As a further inquiry a closed pressure filter, operating without a chamber between it and the point of introduction of the alum, was tapped, both above and below the sand-surface, whereby it was possible to secure samples of water from various depths in the sand body.

Results showed that the alum was not entirely decomposed, and consequently the chemical equation not fully satisfied until considerable depths in the sand-bed had been penetrated.

This was to have been expected, in view of the fact that time is an element in all chemical reactions, and a pressure filter, running under the conditions named, allows but small time to elapse after the addition of the alum before the sand is reached.

As already said, the precipitated aluminum hydroxide has a marked tendency to unite with soluble coloring matter, which fact makes the alum process of distinct value for removal of the yellow stain so often seen in surface-waters.

PROGRESS OF SUBSIDENCE IN ROTATED AND IN QUIET WATER.

When the water is so soft as to be deficient in the amount of alkalinity necessary to decompose the alum added, either lime or "soda-ash" is added to the raw water.

These two chemicals must not be considered as always identical in action. "Soda-ash" (which is a carbonate) is most commonly depended upon to furnish the lacking alkalinity, but sometimes it is disappointing; the case apparently demanding a reagent containing the hydroxyl ion which is furnished by slacked lime.

It may well be, therefore, that the failure following the use of one of the above chemicals will turn to success upon substituting the other.

When doing experimental work to determine the best method of treatment for some particular water, it must not be forgotten that, if small experimental filters are used, the annular space between the filter wall and the sand-bed bears a much larger relation to the filter area than is the case with the full-size plant. Consequently a larger percentage of imperfectly treated water must pass into the filtrate.

The cost of erecting a mechanical filter-plant is somewhat difficult to give, for the reason that patent rights enter the estimate. It is true that the Hyatt patent for the use of alum has expired, but there are sundry devices dealing with improvements in the filtering apparatus itself which are protected by patents, and which it might be inconvenient to do without.

Perhaps the fairest general statement that can be made is to place twelve thousand dollars per million gallons daily capacity as the basis price for a first-class plant, and to alter that figure as local conditions may demand. Reference to costs will be found on page 134.

Filters can be erected for half the above amount, and they do good work for manufacturing purposes, but their bacterial efficiency is low and the water used for washing is higher than in the best forms of apparatus.

The cost of operating a mechanical filter-plant must of necessity be a variable quantity, but it will run not very far from four dollars per million gallons of water filtered. The value given in Johnson's estimate will be found on page 133. A recent figure for the large Cincinnati plant is $3.92. These figures do not include interest on first cost.

The efficiency of mechanical filters in the matter of bacteria removal is practically the same as for the slow-sand type, assuming each to be carefully run. Mr. S. T. Powell, in charge of the Avalon plants, of the Baltimore County Water Co., operates both types of filters with the same raw water.

He reports the following averages for eleven months of 1911:

Type of Filters.	Average Bacteria per Cubic Centimetre, Unfiltered Water.	Average Bacteria per Cubic Centimetre Filtered Water.	Average per Cent of Bacteria Removed by Filters.
Mechanical	2414	8	99.57
Slow-sand	2414	11	99.55

With regard to turbidity removal, and especially the elimination of color, the results secured by the mechanical plants are superior.

"Pin-point" coagulation is often observed as the water grows colder in the late autumn. The flocks become very small and act imperfectly in entangling the suspended matter present in the water. Bacterial efficiency is decreased and aluminum hydroxide even passes into the filtrate. The addition of clay to the water after the alum dose has been well mixed has frequently, but not always, been found a remedy for "pin-point" coagulation. The quantity of clay employed will vary with the occasion, but a dose equal in amount to that of the alum is what should be used at the start and then lowered or raised according to the experimental results. The clay should be added in fine suspension.

An artificial *schmutzdecke* of previously precipitated aluminum hydroxide could, of course, be applied to the sand surface,

but at added cost not only for the extra chemicals, and labor, but also because of the decreased period between washings.

"Pin-point" coagulation usually begins to be troublesome when the water temperature falls to about 40° F.

Increased viscosity of water because of reduced temperature will have an appreciable effect upon the "loss of head" because of the increased resistance offered by the sand-bed.

"Air binding" of the sand-bed is frequently an annoying outcome of winter weather. Cold water dissolves air more readily than that which is warm, and consequently a portion of that held in solution escapes when the water temperature rises in the filter-house.

The bubbles of released air run together and finally burst through the upper sand layers, forming channel-ways which allow the passage of improperly filtered water.

Frequent washing is a remedy, although a somewhat expensive one.

The "excess coagulation" method has been used for a number of years at Springfield, Mass., by Mr. E. E. Lochridge, and found to work well. The alum is applied in a stronger dose during six to seven hours and then shut off for the balance of the twenty-four hours' run. By such method of dosing good results are obtained by the use of less than half the total amount of alum required for the continuous feed.

"The sulphate of alumina must be applied intermittently and at proper intervals. Thus, the same total amount of coagulant which gives excellent results by the method already described has no effect whatever upon the color if applied continuously through the twenty-four hours, or through twelve hours of the day." *

The question so frequently asked, *which system of filtration is it better to adopt, "slow-sand" or "mechanical"* is not capable

* Eng. News, Nov. 13, 1913.

of an immediate answer. Local conditions must first be known.

Either method of filtration, to be of value, requires constant attention. Careful watch must of necessity be kept of a mechanical plant, however small, to secure its running at all, and equal care should be given a slow-sand filter, although efficient supervision is seldom given the smaller beds. Once constructed, they are often left to look after themselves until cleaning is imperative, and then laborers are put upon the work who have never seen its kind before.

It is very poor policy to build a slow-sand bed unless the plant be large enough to maintain a skilled force constantly employed. It may be said that, although relatively expensive for small plants, the slow-sand system rapidly lessens in cost, per unit of capacity, as the plant increases in size. This decrease is not so rapid for mechanical filters.

Other things being equal, slow-sand plants are suited for clear waters, and mechanical filters best for those of turbid or colored character.

The life of a slow-sand filter is practically unlimited, while that of the mechanical type is as yet undetermined.

Finally, it is an easier and cheaper matter to keep the mechanical filter nearer the present requirements as to capacity and to add to it by small extensions as circumstances may demand. So far as bacterial efficiency is concerned, either type will satisfactorily meet the requirements if carefully managed.

Experiments of extended and costly character have been made with a view of securing data whereon to base a decision as to the merits of rival systems of purification, and it is quite reasonable that the question should be asked, Why is it necessary to multiply such tests? Why cannot Louisville and Pittsburgh results be made to do service elsewhere? To a large degree such use is possible, but it must be remembered that waters differ from each other more widely than the bulk of people appreciate. Thus the mere item of suspended matter is a case in point. Not only does the amount thereof greatly

vary, but the changing character of the material causing the turbidity, and especially its degree of fineness, demands particular attention. Two equally turbid waters may look alike to the eye, but the fine suspended matter of one may be easily arrested by a slow-sand bed, while the other may give a filtrate of decided opalescence. Hence the demand for local experiments in important cases.

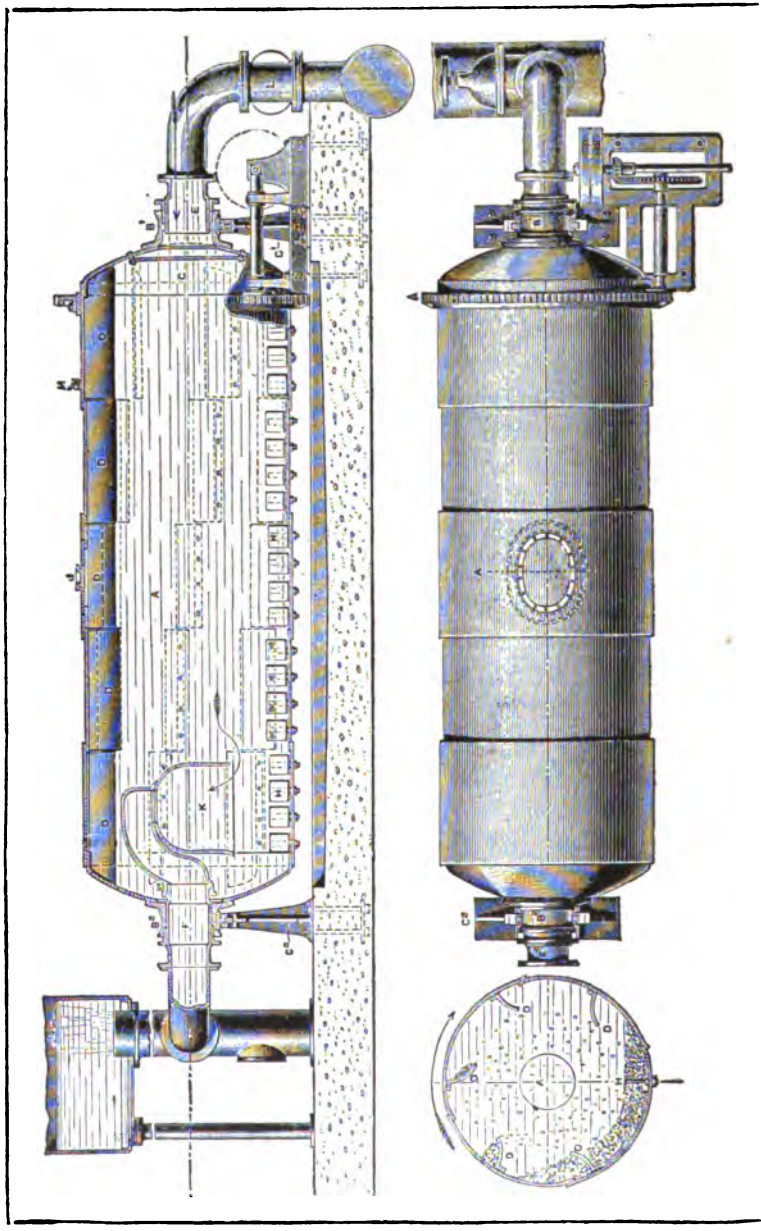
Nearly akin to the filter-plants referred to above is a group of appliances among which is the "*Anderson process*," a device well known in France. In this process the water is forced through iron cylinders revolving on hollow trunnions which serve for inlet and outlet pipes.* On the inner surface of the cylinders are curved ledges running lengthwise, which scoop up iron borings or punchings and shower them down into the water, as it flows through the cylinder. The water issuing from these "revolvers" is exposed to the air, whereby the dissolved iron is rendered insoluble, and by filtration through sand this precipitate is subsequently removed, together with what suspended matter it may have entangled.

Good results are secured by the Anderson process at Boulogne and Choisy-le-Roi, but the use of the system involves an additional and expensive step in the item of revolving machinery, before the water is run upon the sand-filters; and this further outlay of capital is not warranted, in view of the cheapness of some of the other and simpler methods of water improvement.

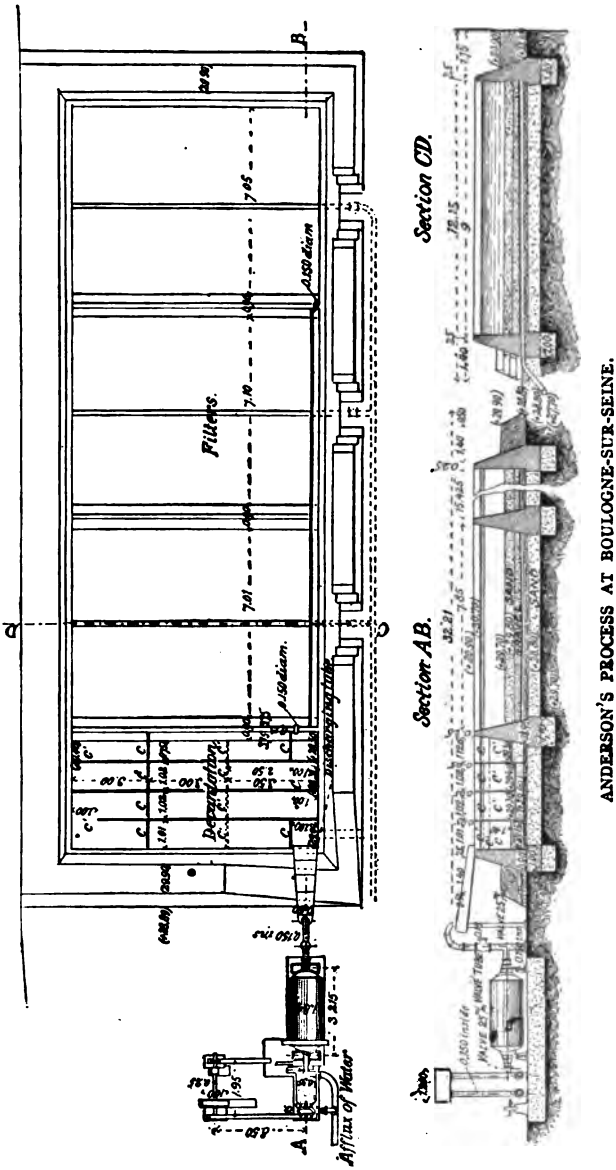
A plan of the Boulogne installation is given on page 184. It consists of two "revolvers" † (4 feet $6\frac{5}{8}$ inches in diameter and 12 feet $10\frac{1}{4}$ inches in length) through which the raw Seine water is pumped. The water takes three and a half minutes to pass through the "revolver," after which it is delivered to an "aerator" consisting of inclined troughs with step-like obstructions to break the current. The greater portion of the insoluble ferric compound formed in the "aerator" is permitted

* See p. 182.

† Only one is shown in the illustration.



"REVOLVER." ANDERSON'S PROCESS.



ANDERSON'S PROCESS AT BOULOGNE-SUR-SEINE.

to deposit in the "decanters" (i.e., long troughs in which the water passes alternately under and over the division-walls) and thence the water passes to the sand filter-beds.

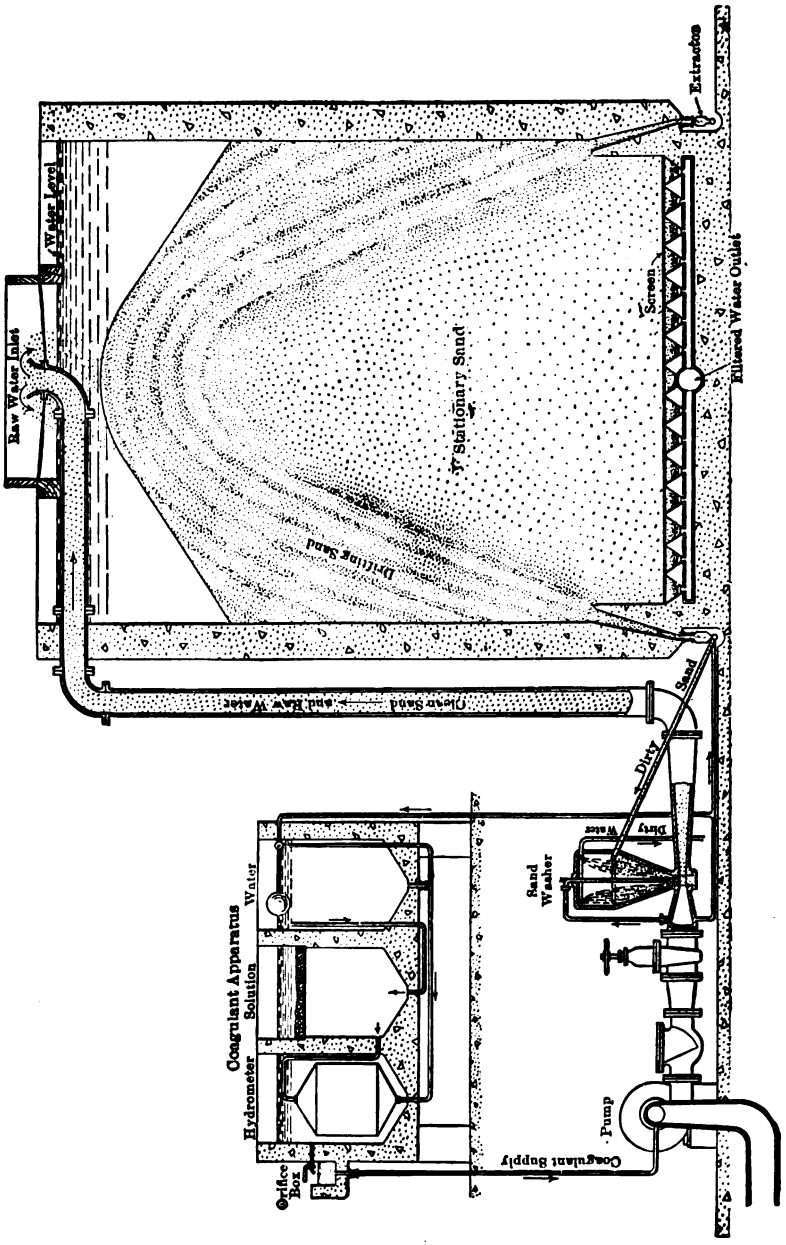
Each "revolver" has a capacity of treating 2500 cubic metres (660,000 U. S. gallons) of water in twenty-four hours. Four grammes (about 62 grains) of iron are required for each cubic metre (264 gallons) of water.

The "Drifting-sand" filter installed at Toronto is almost too new to allow of much being said with reference to its fitness for the work assigned it; but the published experimental results are good, and the plant looks promising, although the up-keep due to wear may be found to be expensive.

The following description by Dr. G. G. Nasmith, of the Toronto Board of Health, is from the *Canadian Engineer*, April 8, 1915:

"The filter consists of a vertical cylinder of reinforced concrete deeper than usual in filter design, and is nearly filled with sand. The filtered-water collecting system is at the bottom divided into a number of small units consisting of a number of hoppers filled with graded gravel held in place by a brass screen fastened down to the concrete. At a distance of 2 feet 6 inches above the under-drain system and all around the filter are a series of hopper-shaped ports down which the drifting sand passes. These ports converge downwards to extractor outlets, with glass inspection tubes so that the operation of the drifting sand can be watched. The extractors are controlled by cocks which can be adjusted to suit the character of the water being filtered.

"The drifting sand from the inspection outlets is collected by a ring main system along which is a current of wash-water which conveys the sand to the sand-washer or sand-separator. The sand-washer consists of a flat-sided hopper-like vessel with glass windows at the flat sides, through which the action can be observed. The sand-washer is attached to the filter supply-pipe immediately over a constriction in it, something like the form of a Venturi meter tube. An opening in the bottom of the sand-washer lets through the clean sand into the



SECTIONAL VIEW OF THE DRIFTING-SAND FILTER.

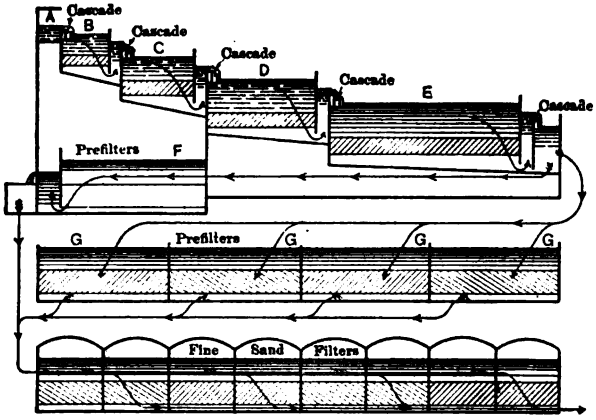
water passing, which conveys it to the filter and maintains the conical heap of sand in it. By the well-known hydraulic principle the pressure in the pipe at the constriction is very much less than on the filter. This difference is sufficient to draw the loose or drifting sand charged with dirt out of the filter into and through the sand-washer and into the supply-pipe, and so maintains the continuous motion of the sand while the filter is in operation. The sand, which by this time has become freed but not separated from the dirt, is led into the sand-washer at about mid-height. The weight of the sand carries it to the bottom of the washer and the dirty water escapes at the top. Near the bottom of the washer is a jet of water which carries the sand downwards into the supply-pipe, displacing the dirty water upwards in so doing. The water used for washing the drifting sand is unfiltered. The plan area of this filter is 143 square feet, or 0.0033 of an acre. The estimated surface of the stationary cone is 306 square feet or more than twice the plan area. The average depth of the sand in the filter is about 13 feet, of which about 54 per cent is drifting. The minimum thickness of drifting sand is about 2 feet 6 inches, and the maximum 10 feet. The minimum thickness of the stationary sand is 2 feet 2 inches and the maximum 13 feet.

"The sand used was a local sand containing a large proportion of limestone, and was prepared principally by screening out the coarser materials and washing away the finer. The physical analysis of this sand shows its effective size to be .4 m.m. and its uniform coefficient 2.7, and was passed through a sieve of eight meshes per lineal inch. In the drifting sand the coarser particles tend to collect in the planes of maximum travel and the finer materials to drop through the coarser, thereby offering the coarser materials to the water first and the finer materials later."

The Puech-Chabal system of filtration is closely allied to some of the processes already described. It consists of a series of sand-beds progressively increasing in area and also in fineness of the sand grains. No coagulant is used. In a word, it is a

refined "scrubbing" system, ending in a slow-sand bed. One of its advocates makes use of the following illustration: "If one desires to rinse out a beaker containing 1 c.c. of sulphuric acid, it is better to divide the wash-water into three or four portions and apply these in succession." A conception of the arrangement of the series of filters may be had from inspection of the following diagrammatic view and the cut on page 188, both taken from a reprint sent the writer by Mr. Walter Clemence, author of a paper on the plant at Madgeburg, Germany, published in *Engineering*, Jan., 1910.

A number of rather large plants of this type are in opera-



DIAGRAMMATIC VIEW OF PUECH-CHABAL FILTERS.

tion in Europe, but the system has no foothold in America, nor is there likelihood of its being adopted here. Mr. Walter Clemence, a strong advocate of the Puech-Chabal filter, writing to the author regarding the plant at Nanterre, France, says:

"The capacity is 10 million Imperial gallons (12 million U. S. gallons) per twenty-four hours. The total cost of the plant is rather under £75,000 ($375,000)."

This is a high figure for a plant of that size, compared with mechanical filters as built here. As to efficiency, good results are secured, but at least as good can be obtained by the cheaper means at our disposal.

The "Non-submerged Filter" occasionally seen in France, especially at Chateau d'Un, is practically unknown to the American public. It is simply a "sprinkling filter" and reminds one of the devices seen at sewage-disposal plants; differing from them in having fine sand instead of broken stone for the bed and in having the water applied continuously in spray instead of intermittently.

Although the results are good, the volume of output is low

PUECH-CHABAL FILTERS, SHOWING CASCADES. MAGDEBURG, GERMANY.

and the expense per million gallons filtered is consequently high. It can be considered only for a small supply.

CHLORINATION

The use of chlorine, either free or as a hypochlorite, is purely a matter of disinfection. Protection is offered against objectionable bacteria, but improvement in the physical or chemical character of the water is not contemplated. Therefore the process is commonly utilized as an adjunct to some

previous treatment and is not very often used alone, except as a temporary expedient. Its employment began about 1909 and has spread with rapidity, so that to-day it is the usual thing to find municipal water works either actively making use of chlorination or at least provided with means of quickly doing so upon emergency.

"*Bleach*," so-called hypochlorite of lime, $CaCl_2O$, is the form in which chlorine is most frequently administered. The sodium salt NaClO, formed by electrolyzing a common salt solution, has been used, but not as widely as the calcium compound. The manner of using "bleach" is to extract it with water and then add the more or less clear liquid to the water supply immediately before distribution to the consumers. If filtration be a part of the water treatment, the "bleach" solution, or "hypo," as it is commonly called, should be added in the clear-water basin, that is, after filtration is accomplished. This is important, for the reason that color and suspended matter use up a large quantity of the chemical and heavy doses are required to secure satisfactory bacterial results in colored or turbid waters.

Stock solutions of the "bleach" are made up of a strength varying in different places from one-half to two per cent; these are stored in suitable tanks, and are tapped therefrom through accurately standardized orifice boxes. Except for emergency plants, which are built of wood, the "bleach-tanks" should be of concrete to avoid corrosive action.

The dose of "bleach" required is stated in parts per million of "available chlorine," for the reason that although the chemical is supposed to contain about one-third of its weight as chlorine, yet it will vary in strength with its age and method of packing, thus requiring frequent analysis. Stated in the form above, the ordinary dose for clear water is about 0.35 p. p. m. "available chlorine." For colored or turbid waters the dose would have to be increased.

Overdose of bleach is to be carefully avoided, as its peculiar taste and odor will be noticed and complained of by the consumers. The sense of taste is more delicate than that of smell

for its detection. People differ as to their ability to notice its presence, but a dose of from 0.5 to 0.6 p. p. m. available chlorine will be tasted by some persons, while nearly twice that quantity will be required to enable them to detect the odor.

This is on the assumption that the water is clear, for, as has been said, heavy doses of bleach are used up by strong color or turbidity.

Removal of the chlorine taste may be accomplished by the subsequent addition to the water of a solution of sodium thiosulphate ($Na_2S_2O_3$), the amount used being a weight of the crystallized salt equal to that of the available chlorine employed. This quantity will be in slight excess of the theoretical. Some water authorities believe in even extending the above dose to "half of the quantity of chlorinated lime to be on the safe side at all times and to take care of all reasonable overdosing with chlorine." *

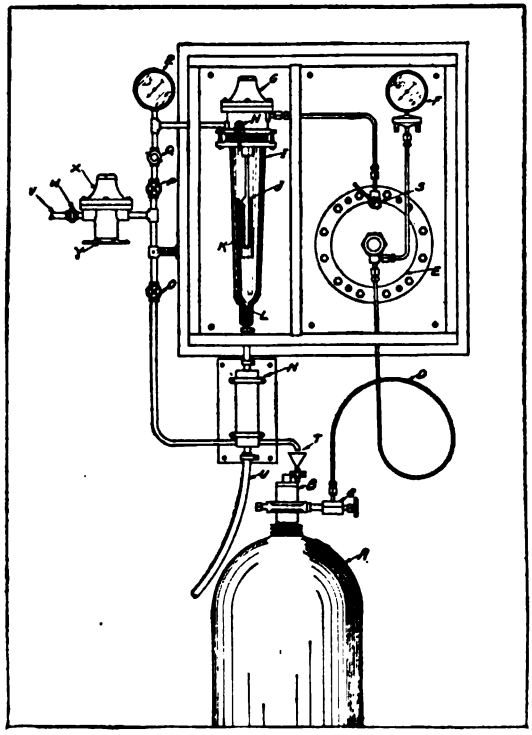
The occasion for the use of the thiosulphate as above, may arise from the accidental addition of an overdose of chlorine as well as from the intentional employment of it in large doses because of the excessive pollution of the raw water, as in times of emergency.

It has been occasionally reported that the use of bleach tends to increase the odor naturally following the presence of odor-producing algæ.

Liquid chlorine is displacing "bleach" in many plants. It ordinarily costs about eight cents per pound, while at normal times "bleach" can be had for a little less than two cents; but as the latter contains only one-third its weight of chlorine the difference in cost is really not great, and ease of administering an accurately adjusted dose of the liquid chlorine makes up for the added expense. Both of these chemicals are now much higher in price, due to the European war.

* Engineering News, 69: 937.

The dry, liquefied chlorine is purchased in steel cylinders under a pressure which varies from 54 pounds per square inch



CHLORINE DOSING APPARATUS. (Wallace and Tiernan.)

A—chlorine tank.
B—valve on chlorine tank.
C—auxiliary valve
D—flexible connection.
E—pressure compensating valve for taking care of the varying pressures in the chlorine tank and also maintaining a constant drop in pressure across the valve *S*.
S—control valve.
G—valve to prevent moisture from getting back into control parts of apparatus.
H—valve to control flow of water and to keep chlorine out of incoming water connections.
F—pressure gauge showing pressure in tank.
J—chlorine flow meter (inverted siphon type).
I—chlorine absorption chamber.
K-L—chlorine solution line.
V—water connection.
P—water valve.
R—gauge.
O—water valve to water seal *N*.
T—water spill.
U—chlorine solution line to point of application.
N—water seal.
X—water pressure reducing valve.
Q-Y—strainers.
Size of apparatus mounted in wall cabinet 20×21 inches.

at 32° F. to 216 pounds at 122° F. and is added to the water by the employment of one of the several automatic devices

now on the market, or else by some less ambitious apparatus contrived by the local management. The chlorine dosing apparatus here pictured is widely used and is efficient. The method of its working will be understood from the lettered description.

Distribution through the water is conveniently accomplished by discharging through a disk of carborundum or similar porous material, which delivers the gas in very finely divided streams of bubbles.

In large plants the labor of preparing the solution of "bleach" and seeing to its proper admission to the water is scarcely felt by the staff of well-trained attendants, nor is the analysis of various lots of the chemical a burden of consequence for the local laboratory; but in small establishments, with but few employees, this work may well be a serious matter, and in such places the change to liquid chlorine becomes a relief, even at a somewhat greater cost.

The action of chlorine upon bacteria differs greatly with the character of the organism, thus *bacillus tuberculosis* is very resistant and the spores of all bacterial forms are practically unattacked except by excessive doses. Naturally such bacteria as are imbedded in organic material are protected from the action of the disinfectant.

In this connection Winslow says:

"We recognize three types of resistance to such oxidizing action as that of chlorine—ordinary vegetative cells, cells with a waxy envelope or of waxy substance, like the tubercle bacillus, and spores like anthrax and *B. sporogenes*, which are still more resistant to the action of the disinfectant. There is danger, therefore, that when the colon bacilli are removed these other types may remain."

A. B. Gillie of this laboratory reports the following results of dosing clear water, artificially seeded with ordinary bacteria, with "bleach" to the extent of 0. 5 part per million of available chlorine.

Intervals of time between dosing with the "bleach" and "sowing" the water for the bacterial count are indicated.

After	0	minutes	220,000	bacteria	per c.c.
"	5	"	1,200	"	"
"	30	"	800	"	"
"	60	"	15	"	"
"	120	"	2	"	"

Similar data are given by E. J. Tully for the clear water of Lake Mendota, Wis.* The interval between dosing and sowing was thirty minutes.

Dose of available chlorine, p.p.m.	Bacteria per c.c.
0.0	8750
0.1	2550
0.3	4
0.5	2
1.0	1

There is no question about chlorine being able to greatly reduce the count of bacteria per cubic centimetre, but although we are interested in this reduction of the general count, we are much more concerned about the destruction of the pathogenic organisms. One German authority says: "It (chlorine) effects their complete destruction when used in a quantity which will not prevent subsequent putrefaction by harmless species";† and that seems to be a practical if not an absolute truth.

Some water specialists have looked upon chlorine as a "dope" for bacteria rather than as a germicide; claiming that its action is but temporary, and Dr. Hale and other bacteriologists have found that "attenuation only of *B. coli* instead of destruction is frequent." ‡

However true it may occasionally be that an apparent after-growth follows the use of chlorine, the fact remains that experiments upon a huge scale, dealing with great centers of

* Amer. J. Pub. Health, May, 1914.
† Wasser und Abwasser, i: 209.
‡ Proc. N. J. San. Asso., Dec., 1914.

population, have shown that, from a practical standpoint, chlorination has stood between the people and disaster.

A very few instances, out of many that might be cited, are here given:

At Erie, Pa., chlorination was adopted March 15, 1911, during a typhoid epidemic due to the pollution of the public water. The beneficial results were at once apparent.

Mr. C. A. Jennings reports the typhoid rate for Kansas City for the years 1900–1910 inclusive as 42.5 per 100,000. Chlorination was introduced in January, 1911. The average typhoid rate for 1911, 1912, and 1913, was 20.

Dr. G. G. Nasmith of Toronto writes:

"Last year our intake plugged with sand and we were forced to short-circuit our water supply and take it from the bay into which all our sewage empties. We had the makings of the largest typhoid epidemic even known on this continent, but fortunately we had hypochlorite to depend on and we came through with a typhoid death-rate of 20 per 100,000 in 1911 as compared with 45 per 100,000 in 1910, an extremely satisfactory showing."

The cost of chlorination, if liquid chlorine be used, is practically nothing beyond the price paid for the chemical (about eight cents per pound) after the dosing machine is once established.

If "bleach" be employed the expense for labor is greater but still the gross sum is small. The cost of the chemical is ordinarily a little less than two cents per pound.

Mr. J. S. Dunworthy estimates that at Erie, Pa., the "average cost of operating the sterilization plant together with the operation and maintenance of the laboratory is approximately $1.00 per million gallons of water treated."

The plant above referred to was one erected to meet an emergency and has now been replaced by a very complete mechanical filter plant with chlorination apparatus added. The cost of maintaining such disinfecting addition to a filter plant is practically nothing beyond the cost of the chemicals.

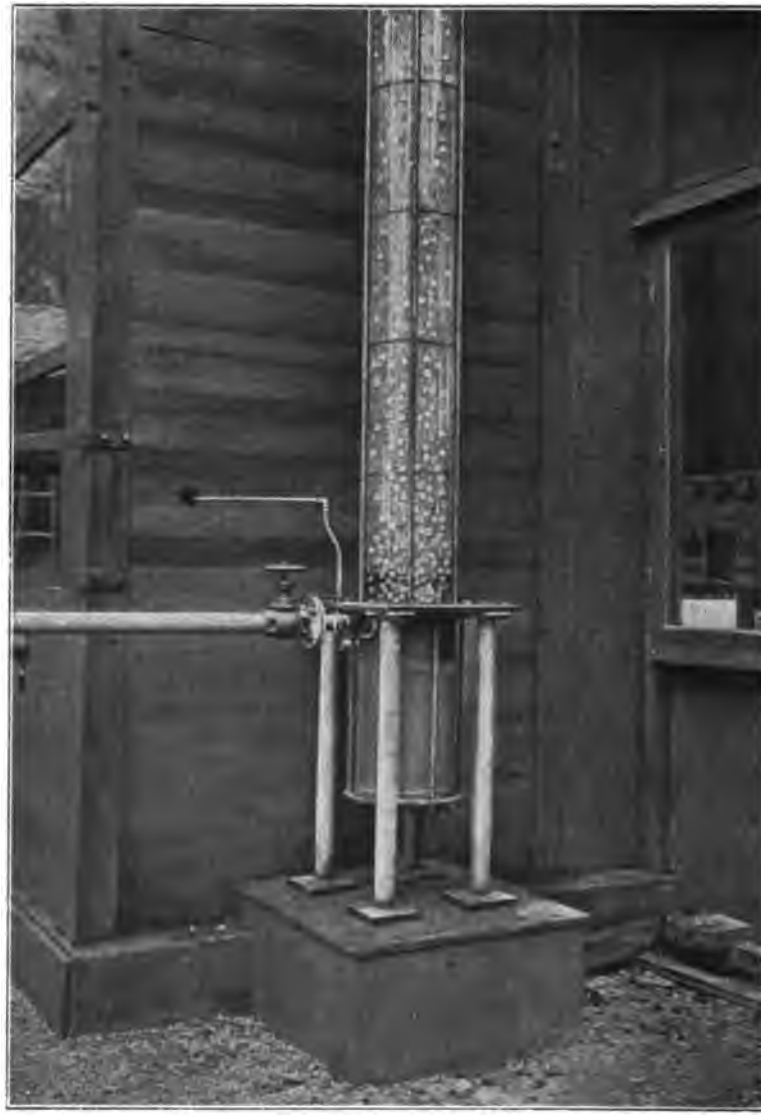
Swimming pools are now so widely in use that it might not be out of place to say that some care should be taken to make their waters as nearly potable as possible. Many of the bathers swallow more or less of the water accidentally, and some of them intentionally do so. The pools are of two kinds, those operated on the "fill and draw" plan, where the entire body of water is wasted after an interval and the basin is then refilled, and those where the water is changed only after long periods, but is continually pumped through a filtration plant using alum, or through some other kind of purification apparatus. The pool at the Rensselaer Polytechnic Institute (100,000 gallons capacity) is of the latter type, the water being continually circulated through three very complete filters. "Bleach" is added in dry form to the surface of the water every week, the dose being 1 part per million of available chlorine. The result is satisfactory.

OZONE

Ozone, an allotropic form of oxygen, is an active agent, both chemically and as a germicide, because of the readiness with which it furnishes atomic or nascent oxygen. There are sundry ways in which it may be prepared, but the one of importance here is that by which electric discharges are passed through oxygen or atmospheric air. Because of that method of preparation, ozone strongly appeals to the public as a safe and proper agent for water purification; and such it would be were it not for the difficulty of securing intimate contact between the ozone and the water to be treated, for the expense attending its use, and for the further reasons that it does not remove color with certainty, and its effect upon turbidity is slight. It cannot, therefore, be used alone, except upon a clear and colorless water.

To a certain degree, however, color and turbidity are altered by ozone. It is a strong oxidizer, hence some bleaching naturally follows its use and there may be a slight lessening of turbidity, due to action on suspended organic particles.

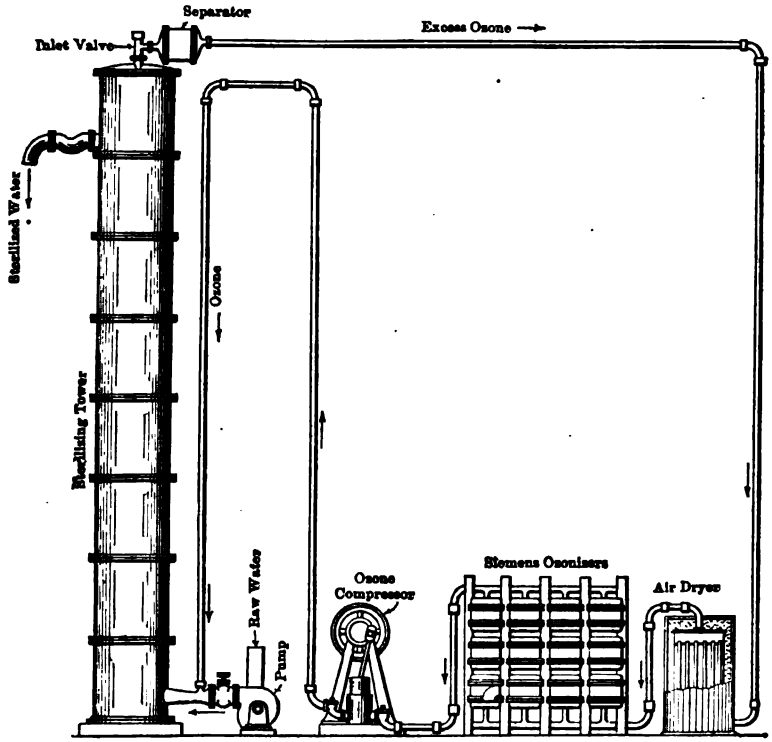
Expense is the serious objection to the employment of



OZ NE STERILIZING TOWER NIEUWERSLUIS, HOLLAND.

this gas; not only because of the first cost of apparatus and the power necessary to produce the necessary electricity; but also on account of the expensive up-keep and the high-priced labor required.

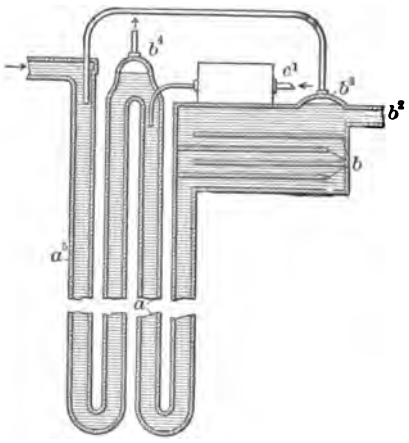
Stated tersely, the ozone process consists in "ozonizing"



DIAGRAMMATIC ARRANGEMENT OF THE DE FRISE SYSTEM AT ST. MAUR, PARIS.
(From the paper of Dr. Samuel Rideal before the Royal Sanitary Institute.)

atmospheric air by means of a silent electric discharge and then bringing such ozonized air into intimate contact with the water to be treated. It would seem a simple matter to accomplish the second step, but ozone is only slightly soluble in water, so that intimate contact has to be accomplished by distributing fine bubbles of the gas through the water in a very thorough manner.

Mixing the ozone and water is secured in the De Frise system as shown by the diagrammatic illustration on page 197, the water and ozone enter at the same point and mingle in the sterilizing tower, while in the Vosmaer apparatus the water flows downward through the tower and the ozone starts at the bottom and flows upward. Such a tower at Nieuwersluis, as seen by the writer (see p. 196), was of glass, but that was manifestly only for exhibition purposes.



THE HOWARD-BRIDGE MIXER.

Raw water enters the pipe a^5 drawing, by suction, unabsorbed ozone from b^3. The waste gases escape at b^4. The current of water in a sucks fresh ozone into itself from the ozonizer c; and after passing around the baffle plates in b, the purified water escapes at b^2.

The Howard-Bridge mixer, page 198, is another device built with a view to secure good contact between the ozone and water.

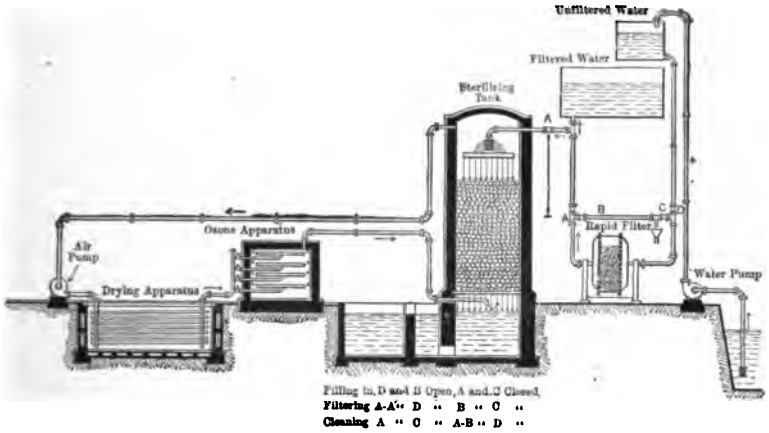
The air required for the ozone production should be dry, but not completely so, inasmuch as a very small quantity of aqueous vapor is beneficial, according to the researches of Arrhenius. This drying was formerly accomplished by the use of some drying agent, such as sulphuric acid or calcium chloride, but is now secured by refrigeration.

The devices employed for the ozonization of air and the

means of administering it to the water are too many, and their description too voluminous, for insertion here. Reference must be had to the monographs on the subject.*

Plants of large size have not been erected in America, so that opportunity has not been offered here for large-scale study of the process. The plants at Ann Arbor, Mich., and Lindsay, Ont., have been discontinued. A considerable number have been installed in Europe and have been examined while working by such men as Rideal, Gerard, and others.

Rideal found the De Frise system at the Paris waterworks



ARRANGEMENT OF THE MARTINIKENFELD PLANT.
(From report of Dr. J. J. de Kinder.)

of St. Maur giving very successful results. Water from the River Marne is used after sedimentation and filtration. After ozonizing it is a "well-aerated brilliant liquid of natural bluish tint and quite inodorous," containing but one or two innocuous organisms and no *B. coli*. The absence of *B. coli*, and pathogenic organisms as well, in ozone-treated water has been frequently observed, and the expression "selective" has been often used to describe the action of the gas upon that type of bacteria. For instance, the following figures are given by the United Water Improvement Co. It will be observed

* See in this connection a full article in Engineering News, 63: 488.

that the effect upon "color" is variable and that the action upon "turbidity" is *nil*. In all cases the character of the substances producing color or turbidity will alter the effect of the gas.

TABLE SHOWING THE EFFECT OF OZONE ON WATER

Bacteria per c.c.			Coli.		Color.			Turbidity.		
Raw.	Ozonized.	% Removed	Raw.	Ozonized.	Raw.	Ozonized.	% Removed.	Raw.	Ozonized.	% Removed.
2,460	26	98.95	Present	Not found	22	5	77.28	20	20	00.0
2,800	12	99.58	"	"	30	15	50.00	40	40	00.0
1,100	5	99.95	"	"	17	0	100.00	15	15	00.0
1,270	6	99.53	"	"	35	15	57.15	15	15	00.0
1,200	0	100.00	"	"	12	0	100.00	17	17	00.0
59,000	680	98.85	"	"	65	40	38.47	400	400	00.0

Ozone is not only destructive of bacterial life, but, in the quantity required for water improvement, is harmless to life of the higher orders. Moreover, by its very activity, it is self-destroying, and any excess is quickly disposed of. These characteristics are strong recommendations for its use in the betterment of water.

The ozone concentration is a term signifying the number of grams of ozone contained in one cubic metre of ozonized air. The following table, prepared by the authorities in charge of the examination of the De Frise plant at St. Maur, gives the concentration there used together with sundry other data.*

Concentration Grams of Ozone per Cubic Metre Air.	Cubic Metres of Air Used per Cubic Metre of Water.	Total Ozone Used in Grams per Cubic Metre of Water.	Bacteria per c.c. Before Ozonization.	Bacteria per c.c. After Ozonization.
1.6	1.383	2.216	800	2
1.04	.....	2.035	850	4
.98	2.077	1.352	2682	3
.88	1.537	2.04	3732	7
1.	1.003	1.	2886	9
.835	1.003	0.693	2886	45
1.12	1.037	1.61	4445	14
1.43	0.831	1.188	145	2

* See J. Franklin Institute, May, 1907.

This "dose" of ozone required at St. Maur is given in the third column of the above table. The amount of this dose will vary somewhat with different waters; thus at Brussels, Gerard secured good results by the use of 0.3 gram per cubic metre (264 gallons) of water. He employed sterilizing towers five metres high arranged with multiple diaphragms to increase the bubbling of the ozonized air. As Chassy has shown, it is much cheaper to employ a large volume of feebly ozonized air rather than a smaller volume with a high concentration. "To obtain a concentration of seven per cent, ninety times as much energy is required as for a concentration of one-half of one per cent."

The cost of ozone treatment is a very vexed question that has not yet reached a satisfactory solution. The process is in competition with the sundry methods of filtration and with sterilization by chlorine. There is no question about its being greatly higher in price than the latter, although it certainly possesses the advantage of presenting a more advantageous system of procedure, considered from the popular viewpoint. As compared with filtration, the question naturally arises, inasmuch as clarification of the water is usually required before ozone can be applied, why not increase the efficiency of the filter plant, at a slightly greater expense, and omit the ozone altogether?

Mr. I. M. de Varona conducted work with the experimental plant erected for the City of New York and found the cost amounted to the prohibitive figure of about twenty dollars per million gallons of water treated. These figures were violently attacked by the friends of the process. One of them, Mr. Bridge, referred to the results secured by Dr. Erlwein in Germany, where, using 1.3 gram of ozone per cubic metre of water treated, the cost was one-half a cent per cubic metre, or $18.92 per million gallons, using an experimental plant, and an estimated cost as low as $7 per million gallons, if a plant of ten million gallons capacity were employed.*

Prof. Leon Gerard of the University of Brussels made a

* J. Franklin Inst., May 1907.

full report upon the ozone process plant at Breda. He fond that the cost for the ozone treatment, exclusive of any preliminary treatment or interest charges, was $8.86 per million U. S. gallons.*

Miquel reports to the Paris Municipal Council, that "the process has been found capable of eliminating a large proportion of the bacteria present in water of various descriptions and of permanently destroying with certainty the germs of *bacillus coli*, which possess greater resisting power than the Eberth bacillus and the cholera *spirillum*. The cost of this treatment is stated, in dealing with large volumes, to be about 1½ centimes per cubic metre, say $15 per million gallons.†

S. T. Powell gives the following data for the Herring Run plant near Baltimore, which is a ten-million gallon unit under his observation.

With an ozone concentration of 1.05 (i.e., 1.05 grams ozone per cubic metre of air) the bacteria per c.c. were reduced from 2720 to 25, a percentage removed of 99.1.

He places the installation cost at $5000 per million gallons capacity and the maintenance at $4 per million gallons delivered, assuming interest at 5 per cent, depreciation at 5 per cent, and electric current at 3 cents per kw. hour.†

ULTRA-VIOLET LIGHT

Ultra-violet light is the latest contribution to the list of processes for water purification upon a considerable scale.

It consists, in a word, of the exposure of the water in thin layers, and at short range, to the light of an electric mercury vapor lamp with walls of quartz. Usually provision is made for more than one exposure of the same water to the light.

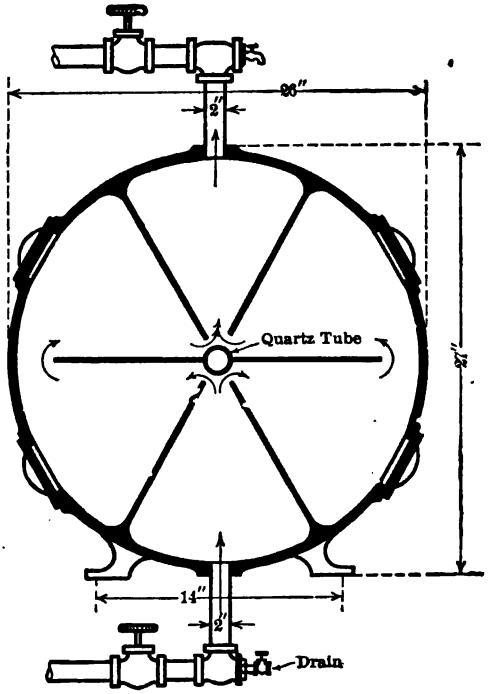
The illustrations which follow are obtained through the courtesy of the R. U. V. Company.

"In this apparatus the lamp is enclosed in a box, through which the clarified water from the roughing filters runs. This

* La Technologie Sanitaire, March 15, 1905.

† J. N. E. Water Works Asso., 29:87.

box is provided with baffle plates, which cause the water to pass by the lamp in the center more than once, so that there is assurance that every particle of the water will be within the range of the ultra-violet rays some time during its passage through the circular box. The lamp itself is separated from the water by windows of quartz glass, which has the property



ULTRA-VIOLET RAY APPARATUS.

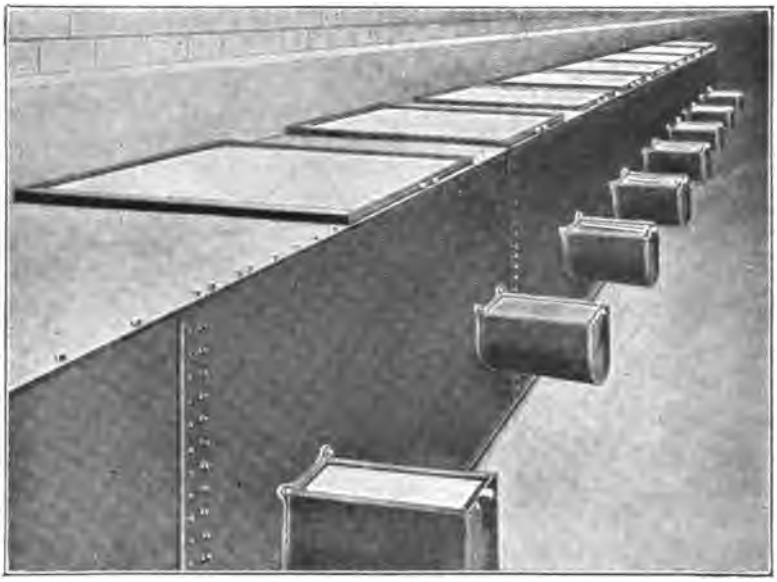
of absorbing only a negligible minimum of the ultra-violet rays thrown out from the mercury arc lamp." While quartz is transparent to these rays, ordinary glass is opaque.

For plants of large capacity a canal installation is used such as shown herewith:

This system of water purification resembles the ozone method in that it requires the water to be clear and colorless

before the light can be efficiently applied. It is more necessary to remove color and turbidity before using the ultra-violet ray than it is to insure their absence when about to employ ozone. The ray does not penetrate far even through clear water.

The cost of sterilizing with ultra-violet light will depend upon the local price for electric current, together with interest



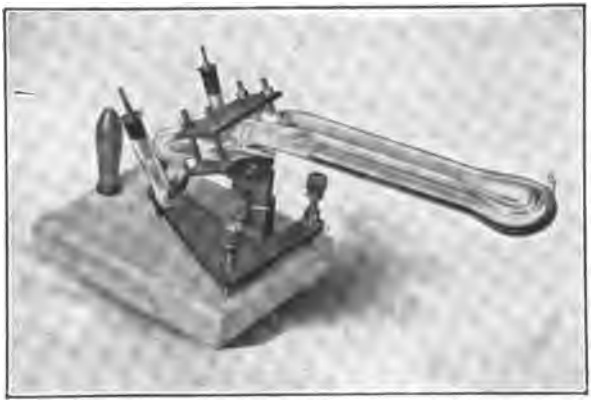
STERILIZING CANAL WITH TEN LAMPS IN SERVICE IN THE CITY WATERWORKS OF LUNÉVILLE, FRANCE.

The lamps here employed are of the "pistol" type, and are inserted opposite baffles in the canal. See illustration on next page.

charges for the first cost of the plant. This latter item will depend upon the type of pre-filters erected to remove color and turbidity from the raw water. The staff required to manage the filters will be enough to look after the sterilizers as well. Inasmuch as some form of filter is usually a necessity, the question arises, as in the case of ozone treatment, why not put in a high-grade filter, and dispense with the subsequent portion of the installation? Further development

and experience will doubtless answer this question for both processes.

G. Espitallier,* as a result of investigation, estimated that sterilization could be secured by the employment of 26 watt-hours per cubic metre of water treated, i.e., 264 U. S. gallons. Recklinghausen gives a somewhat larger figure, namely 36 watt-hours per cubic metre of water. The water contained 5000 *B. coli* per c.c.† He also finds that bacteria differ in sensitiveness to the ray, the killing of sundry forms taking place in the following periods of exposure:



VIEW OF PISTOL LAMP.

Staphylococcus	5	to	10	seconds
Cholera	10	"	15	"
Coli	15	"	20	"
Typhoid	10	"	20	"
Dysentery	10	"	20	"
Subtilis	30	"	60	"
Tetanus	20	"	60	"

E. A. Mau of this laboratory found the influence of color in the water to be slight so far as diminishing the action of

* Eau et Hygiene, Jan. 1911.
† Engineering Record, 64: 60.

the ultra-violet ray was concerned. Using extract of dead leaves as a coloring liquid, waters heavily dosed therewith were sterilized by the light, although the time of exposure had to be somewhat extended.

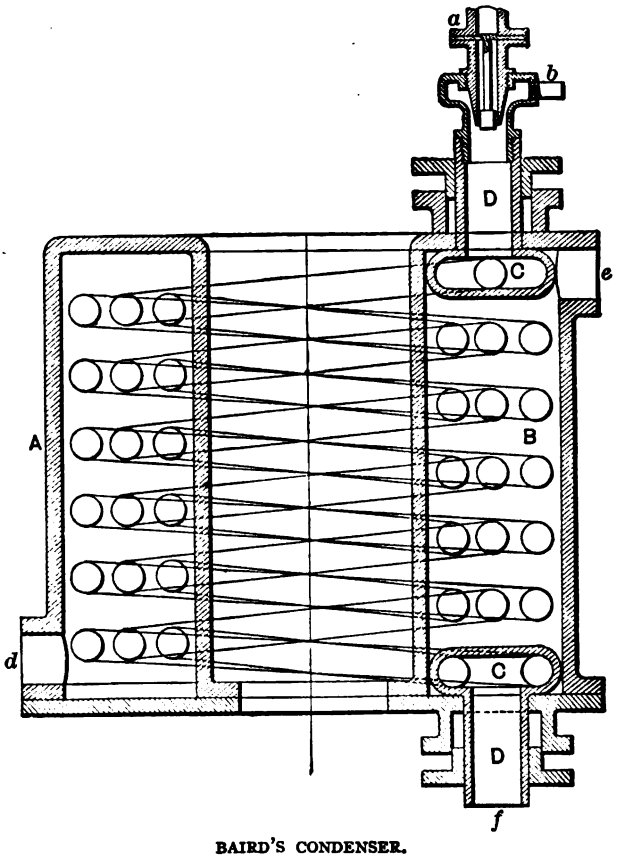
The interference due to turbidity was noted to be more marked than that of color and it was discovered to be the same in degree irrespective of whether the turbidity was caused by organic or inorganic material. Increased velocity of the water was shown to diminish the sterilizing effect of the light, as was to have been expected, because of the resulting shortening of the time of exposure; but the interesting observation was made that a critical velocity existed up to which beneficial results were secured, doubtless for the reason that the eddy currents set up by the quicker flow carried deeper layers of water more certainly within range of the light. This good effect became more than balanced later as the rate of flow became more swift. Irregularities in the bottom and sides of the flow-channels such as would produce eddy currents, are therefore indicated as of practical benefit.

From the sanitary standpoint, the method of purification of water which excels all others in efficiency is distillation.*

The peculiar taste of freshly distilled water is, however, disagreeable to many, and for that reason the process is not likely to become speedily popular, even if the expense were not too great. Some years ago, in a paper before the American Society of Civil Engineers, Mr. Hill advocated the use of distilled water for city drinking supply, and basing his calculation upon one million gallons daily, delivered by small separate distribution-mains, he estimated that the total cost of the water, interest charges included, would be one-eighth of a cent per gallon, which would be at the rate of $1250 per million gallons. High as this price at first appears, it is nevertheless much cheaper than what is now paid by many people for bottled "spring water."

* Further consideration of this question was had on p. 114.

Distilled water is used for drinking purposes on practically every vessel in the United States Navy, and former Surgeon-General Tryon wrote: "It may be stated that the medical officers of the navy recognize the great value of distilled water in the improvement in health that has followed its intro-



BAIRD'S CONDENSER.

duction, particularly on certain foreign stations." That the present Surgeon-General of the Navy also entertains a high opinion of its value we have already seen.

The apparatus used upon the vessels is one devised by Chief Engineer G. W. Baird, and called by his name. An especial feature of value is the introduction of the steam into

the condenser in such a manner as to drag with it a constant and regulated current of air, thereby causing efficient aeration during the very act of condensation. By this means and the subsequent passage through a bone-black filter, the water loses much of the disagreeable taste above referred to, and by further standing for some twelve hours the taste entirely disappears.

That complete sterilization takes place at the high temperature attained there can be, of course, no question. Even the spores of the now known pathogenic bacteria are rapidly destroyed by exposure to the temperature of boiling water, although those of certain non-pathogenic varieties will resist that temperature for hours.

Some years ago a large multiple-effect distilling plant was erected at Fort Jefferson, on the Dry Tortugas, Fla., to furnish water for the naval station and barracks at that place, and to such vessels of the navy as may make port at that point in need of fresh-water supplies.*

A further illustration of a large distilling-plant may be seen at Gibraltar. The water supply of that town and fortress is normally stored rain-water, but the authorities are always prepared to furnish distilled sea-water in case of need.

Aeration of water has always held in the public mind a position of prime importance as a means of purification. There is unquestioned benefit arising from the passage of water over falls and rapids, and from its being thrown into the air in fountains, but the benefit is not so great as is commonly believed.

Agitation and aeration tend to prevent the abundant growth of algæ, with their objectionable tastes and smells, and helps to shake out volatile or gaseous products of ill-smelling character, so that undoubted improvement in quality of water results from the establishing of a fountain in, or otherwise blowing air into, a too quiet reservoir; but the expectations of those

* See Engineering News, March 20, 1900.

AERATOR AT WEST PARISH FILTERS, SPRINGFIELD, MASS.
(From report of Water Board.)

who hope to thus easily eliminate pollution of a more serious character will not be realized.

A further consideration of the influence of aeration will be found in the chapter on stored water.

Iron removal by the use of aeration and subsequent filtration is resorted to with ferruginous waters which are otherwise fit for general domestic use. As a result of wide inquiry among those interested in water for laundry purposes the writer concludes that more than 0.5 part per million of iron (stated as Fe) is unacceptable for such use. Objection is occasionally raised to a smaller amount.

By blowing air into such waters, spraying them or even by letting them stand freely exposed to the atmosphere, carbon dioxide is reduced and the iron is commonly (but not always) oxidized to an insoluble form easily removed by filtration.

Coke filters, or tricklers, are frequently used to accomplish the aeration and oxidation needed and it has been found that the metallic iron in the coke increases the efficiency of the filter for removal of the iron in solution.*

The simple method of iron removal by aeration is indicated when the iron is present in an easily oxidized form, such as the carbonate. The process may be seen in operation at Asbury Park, N. J., and also at Far Rockaway, N. Y.

At the former plant the water is derived from deep wells (400 to 1100 feet deep) and is raised by an "air-lift." After reaching the surface it is forced through pressure filters of the ordinary mechanical type. Alum is not used. At Far Rockaway the principle is the same, only an "air-lift" is not required. Sufficient oxidation is secured by allowing the water to spill from the upturned end of the pump-main, after which it is run upon two slow filter-beds which are open and of the English type. In each of the above cases the result is satisfactory.†

Even if the iron be fully oxidized, it may fail to precipitate,

* J. N. E. Water-works Asso., xi, 278.

† Engineering News, June 4, 1896, and April 12, 1900.

because of there being considerable organic matter present in the water tending to hold it in solution.

Downs reported that the iron in a colored water of the canal zone was in union with organic matter, and utterly failed to be removed by aeration. He was successful in his efforts to take it out by the use of a dose of 1.5 grains per gallon of aluminum sulphate, followed by sedimentation and filtration.*

Should the iron be present in the form of ferrous sulphate, then its removal becomes somewhat less easy.

Sulphate of iron has been successfully removed from the water of Reading, Mass., by the use of lime, followed by aeration and mechanical filtration,† but studies are now under way by R. S. Weston with a view to abandon the treatment with chemicals and resort to aeration and the contact-action noted further on.

In America a number of iron removal plants are in operation, but space can be spared for a brief description of only two beyond those already mentioned.

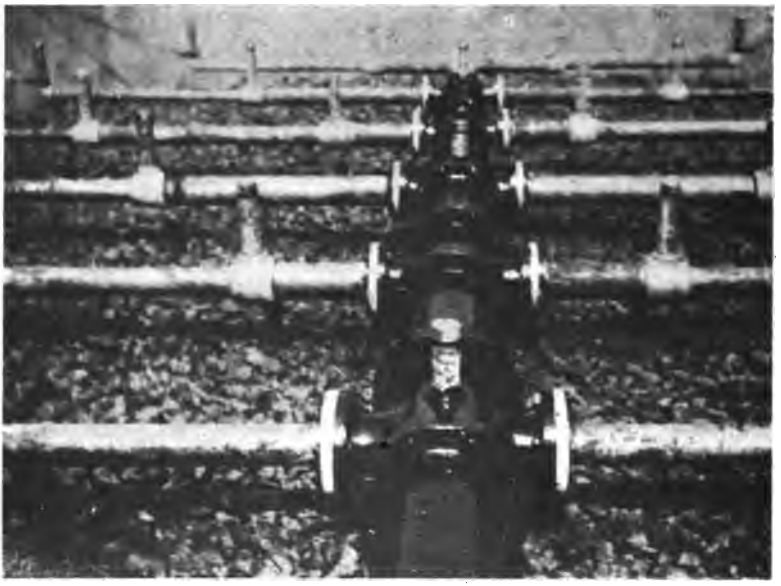
At Middleboro, Mass., the water from the well is pumped to a "trickler" built of concrete, of cylindrical form, thirty feet in diameter and containing a bed of coarse coke ten feet in thickness. The entering water is sprayed upon the coke and after passing the bed, flows to a settling basin and thence to the two filters. Arrangement is made for a yearly flushing out of any excess of iron deposit on the coke by filling the "trickler" with water and then allowing it to suddenly flow to waste.

The two compartments of the filter have a combined sand area of 0.1 acre. The beds are 12 inches of graded gravel supporting 36 inches of sand of 0.31 m.m. effective size. A full description of this plant is given by Professor Weston, J. N. E. Water-works Asso., 28: 27.

The capacity of the plant is one million gallons per day. It cost $18,000.

* Proc. Am. Water Works Asso., 1910.

† Engineering News, June 4th and Nov. 26th, 1896.



COKE TRICKLER FOR IRON REMOVAL, MIDDLEBORO, MASS.

COKE TRICKLER FOR IRON REMOVAL, MIDDLEBORO, MASS. (IN OPERATION)

AVERAGE RESULTS OF OPERATION

(Parts per million)

Determination.	Well.	Settling Basin Effluent.	Filter Effluent.
Color	48.0	22.0	5.0
Turbidity	5.0	3.0	1.0
Iron	1.62	0.46	0.17
Manganese	0.67	0.36	0.27
Hardness	27.3	.....	23.4
Oxygen consumed	1.79	1.53	1.05
Carbon dioxide	41.0	4.2	4.6
Dissolved oxygen	2.95	10.20	9.55

The Middleboro water shows a tendency to increase in the amount of contained iron as is indicated by the following figures given by the Mass. State Board of Health:

1893, 0.7; 1894, 0.237; 1895, 0.187; 1896, 0.288; 1897, 0.227; 1898, 0.408; 1899, 0.329; 1900, 0.489; 1901, 0.487; 1902, 0.841; 1903, 0.922; 1904, 1.372; 1905, 1.17; 1906, 1.126; 1907, 1.209; 1908, 1.349 parts per million.

This is a condition often observed, especially in districts where the ground-water has been "over-pumped," and it is a discouraging one if an iron-removal plant be not at hand. With such a plant available, however, the increase in dissolved iron is unimportant, and may be even beneficial, inasmuch as a reasonably large amount of iron is easier to remove than a small quantity.

The plant at Lowell, Mass., designed by F. A. Barbour, possesses a coke bed ten feet deep, an intermediate sedimentation basin of one hour capacity and a sand filter three feet deep; but the point in which it differs from the Middleboro plant is the way in which the coke bed is used. In the latter city it is employed as a sprinkling or trickling filter, the water being sprayed over its surface as already described; while at Lowell the coke is used as a "contact-bed," much after the fashion of the sewage treatment-device bearing the same name.

The surface of the coke is not flooded by the applied water, nor are any pools formed thereupon; but the filter is "back flooded" to within a short distance of the coke surface and the

water is applied in streams about one inch thick, so that there is much "contact" and only partial aeration by spraying. The amount of both "contact" and aeration can be adjusted at will. The size of coke is about two inches.

Mr. Barbour has shown that the iron and manganese present in the Lowell well water cannot be removed by aeration and direct application to sand filters; nor by aeration, sedimentation and sand filters; and that excessive aeration by a sprinkling filter is not adapted to the treatment of the water; but that a coke bed, used as a contact-device in the manner noted above, followed by sand filtration, will remove the iron and manganese successfully and economically, at a cost of $7.65 per million gallons, including interest, depreciation and operating charges. See his report to the Municipal Council, 1914.

Manganese in water will cause a troublesome turbidity upon exposure to air and will make the associated iron somewhat more difficult of removal.

The method of treating such a water is similar to that employed for one containing iron alone as has been shown, but the separation is slower and therefore the contact-action should be more prolonged.

Reference is made on page 485 to the Permutit method for manganese removal.

Carbon dioxide removal from water is required if it be present in considerable quantity, for the reason that the gas will strongly attack lead pipe and lead to "plumbism" or lead poisoning, and it will act as a corrosive when the water is used in boilers.

Lime is the chemical agent that naturally suggests itself but the fact that its use hardens the water is a disadvantage. The amount that Barbour was obliged to use at Lowell (1.5 grains per gallon) so increased the hardness that he found it more expedient to displace the dissolved gas by aeration.

He employed small nozzles $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter which threw a very fine spray and caused a very effective removal of

the carbon dioxide, reducing it from 45 parts to 3.3 parts per million. The pressure at the nozzle was five pounds per square inch. The cost did not exceed $2.25 per million gallons, including interest, depreciation and pumping.

This cost is less than that of the lime treatment, if consideration be taken of the expense due to the extra soap required to meet the added hardness.

Household filtration on the domestic scale is in very general operation, yet satisfactory results are obtained in but a small percentage of cases.

The companies manufacturing the mechanical filters already mentioned make sizes intended for domestic use, but the skilled labor furnished by a city employee whose sole duty it is to attend to the public plant is very rarely obtainable in the average household; consequently the filter is neglected or mismanaged, or both. In short, filtration, to be effectual, should be municipal. A house filter that has come widely into use, and upon which very many people pin their faith, is the well-known "Pasteur." It is commonly operated under the pressure of the city mains, but may also be arranged to work without additional pressure beyond that of the atmosphere. The cut herewith given shows its simplest form, and, for those unacquainted with its use, it may be said that it consists of a cylinder of fine unglazed porcelain (called "candle" on account of its size and shape) enclosed by one of metal; and that, connection having been established between the latter and the supply-pipe, the water is forced through the pores of the porcelain to the inside of the cylinder (the so-called candle), whence it drops into the reservoir, leaving the suspended matter as a coating upon the "candle's" exterior surface.

Examination of the efficiency of the Pasteur filter has been carefully done by a number of investigators, with results that may be summarized as follows: Water can be completely sterilized by filtration through unglazed porcelain, but the filtration must not be continued for many days at a

time. The length of time during which a sterile filtrate may be obtained will depend upon the temperature of the filter and its contents. Thus, according to Freudenreich, at a temperature of 59° to 64° F. the filtrate was sterile for from fifteen to twenty-one days, at a temperature of 72° F. it was sterile during nine days, while at a temperature of 95° F. it remained sterile only five days.*

PASTEUR FILTER.

Water-pressure is not a factor in causing germs to pass through the porcelain, for their method of penetration is one of development rather than a transporting of initial bacteria; in other words, they "grow" through the filter. Even when the pressure is nil they accomplish the passage in the usual length of time.

Horrocks denies this and says: "The *B. typhosus* is not able to grow through the walls of a Pasteur-Chamberland candle, and, if proper care be taken to prevent the direct passage of organisms through flaws in the material and imperfections in the fittings, the Pasteur-Chamberland filter ought to give complete protection from water-borne disease." †

In this connection it must be noted that filtration will not stop the active principle of every disease, infantile paralysis for example.

From a consideration of all the data given the line of management for a "Pasteur" becomes plainly evident. The "candle" and its rubber packing should be removed at least once a week, thoroughly washed, and then boiled for half an hour before being reset in position.

Especial care should be taken that there are no flaws in the "candle" and that the rubber packing make a tight fit, as otherwise the filtrate may pass around rather than through

* Centralblatt für Bakteriologie, xii. 240.

† "An Introduction to the Bacteriological Examination of Water." By W. H. Horrocks.

the porcelain. The filter should not be located in too warm a place.

The lateral connecting the filter with the supply-main should be of tin or iron, as the slow action of the filter allows the water to remain for a considerable time in contact with the metal.

Many types of household filters are of such character as to preclude the possibility of sterilization, and some of them it is even impossible to clean without the entire renewal of the filtering material. Such defects are necessarily fatal to proper filtration. The stone filters one sees at times, where the water is caused to drip through fine-grained sand-rock, or similar material, act as mere strainers and are absolutely unreliable.

The author demonstrated that a sponge filter, after use for a month furnished a filtrate containing 121,200 bacteria per cubic centimetre, as compared with a count of 540 per cubic centimetre, in the unfiltered water. Household filters of many types are so seriously contaminated that a water cannot but be rendered worse by passage through them, and yet such appliances are in full use, and greatly trusted on account of the apparent clearness of the water drawn from them.*

The common belief is that a filter, once established, is good for all time, and an amount of carelessness is permitted in otherwise well-organized establishments, that would almost stagger belief.

For instance during the cholera epidemic at Lucknow in 1894 out of 646 members of the East Lancashire Regiment 143 were attacked by cholera and 92 died. Direct proof was had of the infection of the barrack-room filter.†

Much stress is often laid upon the purifying effects of animal charcoal, and the great quantity of occluded oxygen the fresh charcoal contains fully justifies for a time the high praise

* A very full report upon the various types of filters in use, by Woodhead and Wood, may be found in British Medical Journal, vol. ii, pp. 1053, 1118, 1182, 1375, and 1486.

† See "Applied Bacteriology," by Pearmain and Moor, p. 312.

given it, but such material is nearly impossible to cleanse, and it has been repeatedly shown that a more objectionable appliance could scarcely be found, from a sanitary point of view, than a neglected charcoal filter. For instance, Frankland finds that in the case of such a filter having been in use a month, the filtrate contained 6958 bacteria per cubic centimetre, as against 1281 per cubic centimetre in the unfiltered water.*

A similar record is made by Percy Frankland, of water passed through a filter composed of six inches of animal charcoal, in a state of fine division:

Period.	Organism per Cubic Centimetre.	
	Unfiltered Water.	Filtered Water.
Initial	Very numerous	none
After 12 days	2800	none
After 1 month	1280	7000

For certain special uses, however, the carbon filter is valuable. Thus the writer recommended passing an already filtered river-water through a layer of fine coke in order to remove the last trace of color which was not extracted by the use of alum. An absolutely colorless water was required for the manufacture of a particular grade of paper, and it was secured by such means.

The good old household remedy of boiling a suspicious water is always available, but unfortunately it is but seldom applied. As an illustration of its value it is worth noting that during the cholera outbreak at Lucknow, referred to above, among the members of the East Lancashire Regiment, there was no cholera whatever in company E. This company was the only one which boiled the drinking-water.†

Emergency purification methods have to be adopted upon occasion, as when accidental pollution of a distribution reser-

* Chemical News, lii, 27.

† Rideal, "Water Purification," p. 151.

voir occurs, or when the force of circumstances demands the use of water known to be impure. This is frequently a military necessity.

Disinfection of a small reservoir is best secured by wasting the water and sprinkling the sides and bottom with strong solution of bleaching powder.

Such a treatment was extended to the street mains at Maidstone, England, at the time of their great typhoid epidemic. Disinfection of the pipes was very thorough but so also was the damage to the pipe fittings, as the strength of the solution used was much too great.

After the great flood of 1913 at Columbus, Ohio, Hoover and Scott disinfected the city mains with lime.*

"All water pumped into the city was treated with 1 to 2 grains per gallon of lime in excess of that necessary to neutralize the free and half-bound carbonic acid. This is harmless, does not taste and there was no evidence, except by chemical test, to indicate any causticity in the water. Samples were collected from numerous points in the city, from which it was found that the caustic water had diffused throughout the system in a short time. The river water had 500,000 bacteria per cubic centimetre and showed positive presumptive tests in one to fifty dilutions, while the samples from the mains were negative in 10 c.c. portions twenty-four hours after pumping was resumed.

"When enough lime is added to water to absorb the free and half-bound carbonic acid and to precipitate the magnesium content, the bacteria of the colon and typhoid groups are killed in forty-eight hours after being so treated.

"The germicidal action is effective in from five to twenty-four hours when an excess of ½ to 1 grain per gallon is added beyond that needed to reduce the temporary hardness to the lowest possible figure.

"Intestinal organisms will not live in water containing no free or half-bound carbonic acid."

The inability of *B. coli* or *B. typhosus* to live in the absence

* See Engineering Record, 67:395.

of free or half-bound carbonic acid has been also shown by C. Haller.*

Thresh sterilizes water for the army in the field by adding an excess of "bleach," at least one part of available chlorine per million parts of water, and, after an interval of fifteen minutes, removing the excess of sodium thiosulphate.†

Boiling the drinking water, with subsequent aeration to remove the flat taste, is often practicable during active service and it is efficient.

* Chem. Zentr., 1914: i. 193; also Chem. Abstracts, viii. 2206.
† Lancet, 1914: 809.

CHAPTER IV

NATURAL PURIFICATION OF WATER

NATURE disposes in sundry ways of the various elements of impurity added to water, but by far the most important of these is the process termed "nitrification." This is a change best established by infiltration through soil, a few feet of such passage being capable of doing more to restore a water to its original purity than miles of flow in an open channel.

Nitrification is accomplished by bacteria whose function is to tear asunder the objectionable nitrogenous organic materials, secure their union with the oxygen of the air and thus convert them into harmless inorganic forms, which are at the same time valuable as plant-food.

The conditions under which these little organisms can thrive must be met, otherwise the oxidizing action will quickly diminish or even entirely cease. Darkness is favorable and strong light is fatal to the process. A supply of free oxygen must be at hand, but, as has been pointed out by Drown, a small fraction of the amount normally present in the atmosphere will quite suffice for complete nitrification. The presence of a base is necessary to fix the nitric acid formed.

The action of the nitrifying bacilli is mainly confined to the upper layers of the soil, i.e., to those portions subject to cultivation, and it rarely occurs below a depth of six feet. This diminution in number with depth in soil occurs in the case of other bacteria as well.

One feature of special interest is that the nitrifying organism does not thrive in presence of a great excess of organic matter. It cannot be successfully cultivated in either bouillon or strong sewage. Furthermore, it is noticed that where nitrification is once thoroughly established other germs tend to die out, probably on account of lack of food-supply.

The great importance of this purifying process of nitrification will be better appreciated when we come to consider the question of ground-water, for it is at once apparent that our wells must receive large contributions from drainage material poured into and upon the soil. One thing must be ever borne in mind when depending upon the purifying action of soil, namely, that its power should not be overtaxed by excessive doses of sewage material, and that its use as a filter must always be permitted to be intermittent, so that a proper supply of oxygen may be provided. The importance of aerating the filtering soil between the successive applications of sewage has been abundantly shown by the Massachusetts Board of Health, and the advantages of so doing are demonstrated on the large scale upon all sewage farms.

Sewage for the purpose of broad irrigation is conducted throughout the irrigated district in open conduits of earth, and small side-gates at intervals admit it to the furrows between the rows of growing plants; the gates being opened and the furrows filled whenever, in the judgment of the attendant, the vegetation can appropriate the dose.

The face of the land is all divided into small sections, in places less than an acre in area, and each such division is flooded independently; an arrangement whereby the filtration of the sewage through the soil can be maintained entirely intermittent in character, and nitrification given abundant opportunity for full development.

Any surface-clogging of the ground is avoided by suitable use of the spade. So far as the quantity and quality of the crops raised are concerned, they appear to be very near perfection.

The conclusions reached by the Massachusetts Board of Health are as follows:

"The purification of sewage by intermittent filtration depends upon oxygen and time; all other conditions are secondary. Temperature has only a minor influence; the organisms necessary for purification are sure to establish themselves in a filter before it has been long in use. Imperfect purifica-

tion for any considerable period can invariably be traced either to a lack of oxygen in the pores of the filter, or to the sewage passing so quickly through that there is not sufficient time for the oxidation processes to take place. Any treatment which keeps all particles of sewage distributed over the surface of sand-particles, in contact with an excess of air for a sufficient time, is sure to give a well-oxidized effluent, and the power of any material to purify sewage depends almost entirely upon its ability to hold the sewage in contact with air. It must hold both sewage and air in sufficient amounts. Both of these qualities depend upon the physical characteristics of the material. The ability of a sand to purify sewage, and also the treatment required for the best results, bear a very close relation to its mechanical composition."

We have thus seen that nature makes abundant provision for the removal of pollution from water that is poured upon the soil by oxidizing the objectionable material indirectly through bacterial agencies.

As to the efficiency of those means, so highly thought of by the people at large, and supplied wherever the water passes over rapids and falls, namely, *agitation and aeration*, not so good an account can be given. Does direct oxidation take place, and, if so, to what extent? With a view of obtaining light upon this question, extended series of investigations have been undertaken with results which have produced a negative reply. Perhaps the best known are Prof. Leeds' examinations of the water of the Niagara River before and after passing Niagara Falls. He found no improvement resulting from the passage over the cataract, and it is but reasonable to conclude that direct oxidation does not serve as a factor of any considerable importance in the purification of polluted water.

In this connection, and as a result of his own investigations, Frankland says:

"We are aware that ordinary oxygen does not exercise any rapid oxidizing power on organic matter. We know that to destroy organic matter the most powerful oxidizing agents are required. We must boil it with nitric and chloric acid and

the most perfect chemical reagents. To think to get rid of organic matter by exposure to the air for a short time is absurd."

Bearing in mind the known powers of resistance of the various bacteria, it is difficult to conceive of any appreciable diminution in their numbers resulting from a short-time exposure of the water in the form of spray.

Neither is it easy to see that the beneficial labors of the nitrifying bacillus can be materially aided by the momentary passage of a fall, when we remember the small percentage of dissolved oxygen required for the fulfilment of its task.

That the said nitrifying bacillus can, under any circumstances, accomplish in a water the quantity of work expected of it in a soil is, of course, not to be hoped for.

It must not be assumed, however, that the old and firmly planted belief of the people is entirely false, and that aeration is without any value whatever. Keeping a water well saturated with atmospheric oxygen, either by spraying it in form of a fountain, as at Rochester and elsewhere, or by pumping air into it, unquestionably renders less likely the growth of some forms of algæ, with their accompanying odors and tastes, and also removes, by direct displacement, any foul gases or volatile products already in solution.

The Kensico aerator of the new supply for New York city consists of a concrete basin 460 by 240 feet in area from the floor of which the water is thrown into spray through 1750 nozzles.

It is undoubted wisdom to encourage the existing tendency to aerate public waters, but the true action of such aeration must be always kept in mind, to the exclusion of false and exaggerated notions of its value.

Sedimentation is another purifying process upon which wide dependence is placed. Its consideration properly comes under a discussion of lake and reservoir waters, but a word should be said here with reference to what may be expected of it in the cases of streams and rivers.

With a view of determining to what extent sedimentation can be depended upon for the purification of streams, the following inquiry was undertaken.

Upon four different occasions (covering various conditions of medium, high water, and flood) samples were analyzed from that section of the Hudson River extending between Troy and Albany. The stations at which samples were taken are situated over one mile apart, beginning at State Street, Troy, and ending at Albany, five miles below. Two samples were taken at each station during ebb-tide and in mid-channel; one two feet from the surface and the other, as near as could be judged, two feet from the bottom.

The examination of the samples showed sedimentation at all stages of the river, the average being nearly constant throughout the entire distance.

Such sedimentation was, however, found to be decidedly small. An idea of the amount deposited may be obtained from the fact that average differences for total solids between the upper and the lower samples at the end of the second mile was 3.47 per cent of the total solids in the upper sample.

A review of the evidence furnished by the inquiry leads to the belief that sedimentation as a source of river purification in streams such as the Hudson is not nearly so valuable as has been heretofore held. And it would appear, moreover, that a river mainly clears itself by "running out" the suspended silt rather than by depositing the same upon its bed.

So far as the removal of bacteria from river-water by sedimentation is concerned, it must be remembered that, their specific gravities being only slightly greater than unity, they sink but slowly in quiet water, and of necessity still less rapidly in that which is moving. That specific germs do not all subside during even long distances of flow may be inferred from the typhoid statistics already given.

Freezing water does not completely purify it, as was formerly supposed; neither is it correct to assert that bacteria in general resist low temperature, as was more recently held to be true.

Under the chapter on "ice" it will be pointed out that mechanical exclusion and lapse of time are large factors tending toward purification during the formation and storage of ice; We now recognize that great mortality occurs among bacteria, because of low temperature and pressure, during the process of freezing; and we further find that such mortality will vary with the type of the organism.

As a single instance: ordinary tap water lost sixty per cent of its total bacteria by simply freezing solid. The whole volume of the water was turned to ice; the ice was then immediately melted and the water examined for total bacteria, with the result as above stated.

Mechanical exclusion and lapse of time did not enter in this case and the resulting mortality was due to low temperature and pressure.

This experiment simply shows that a high mortality follows freezing, but the actual percentage is of no great significance, as a variety of numerical results can be obtained, some of them showing a mortality reaching to nearly 100 per cent.

The inadequacy of ice formation as a protection against bacterial pollution is more fully referred to upon another page.

It remains to say a word concerning the *purifying action of sunlight* supplementary to what has been already given on page 65.

Very exhaustive investigations by Prof. H. Marshall Ward show light to have great germicidal action and that "the rays which kill the bacteria are the blue and violet ones. The infra-red, red, orange, yellow, and green are without effect."

"This explains why these organisms are destroyed so much more rapidly by the light of the summer sun than in winter; why a clear blue sky is so much more effective than a hazy one, and why direct sunlight acts so much more quickly than reflected or diffused daylight." *

Investigations upon this topic are as yet uncompleted,

* Chemical News, lxx. 243.

but enough has been done to show the marked toxic effect of sunlight upon bacterial life and its consequent aid to the effort of the sanitarian. For full and detailed information upon the subject the reader is referred to the work of Percy Frankland.* Stated roughly, sunlight is fatal to bacteria sooner or later, the intensity of the action depending upon the kind of germ and the brightness of the light.

Buchner gives a graphic illustration of the action of light, using the typhoid bacillus for the demonstration,† the value of such experiments is far-reaching, and suggestions of sanitary importance naturally follow.

The bearing this point has upon the influence of sunlight upon the self-purification of streams is at once apparent; but it must not be forgotton that a comparatively thin layer of water will cut off an immense deal of the germicidal power of sunlight, and we must consequently restrain our tendency to exaggerate the beneficial action.

In this connection it is worth while studying the antiseptic action (recorded by Procacci) of midday sunlight, in June, upon bacterial life contained in drain-water forty inches deep. The light was passed through the water vertically, side-light being excluded, and the time of exposure was three hours. Comparison tests, kept in darkness, were also made. The results were as follows per cubic centimetre:

	Before Exposure.	Sunshine.	Darkness.
Surface.....	2100	9	3103
Centre.....	2103	10	3021
Bottom.....	2140	2115	3463

The sterilizing action of light upon the upper portion of the water is thus seen to have been marked.

After all the bactericidal action of sunlight has been acknowledged we must recognize that, as a sanitary proposition, the beneficial results to be obtained from it as a water purifier are small indeed. Its power of penetration is too low,

* "Micro-organisms in Water."

† "Einfluss des Lichtes auf Bakterien." Centralblatt f. Bakteriologie, xi. 781.

especially in turbid or in colored waters or when winter has covered the rivers with layers of ice.

Even the ultra-violet ray is efficient only in clear and nearly colorless waters, and then to only very moderate depths.

Self-purification of Streams

Pettenkofer expressed the opinion * that "ordinary sewage may be, without hesitation, turned into any river or brook whose volume is fifteen times the volume of the sewage, and whose velocity is not less than that of the stream of sewage. Under these circumstances the necessary dilution and self-purification take place after a short flow."

If this were only true, the vexed question of sewage disposal would be largely disposed of, and enormous sums of money now expended in such disposal would be saved. That it is very far from being safe practice is evidenced by such statistics as have already been quoted showing the serious pollution of large rivers by small streams of sewage inflow. It has been shown (page 28) that twenty-six miles of flow was not enough to protect Albany from the contaminated sewage of Schenectady, even when the rivers in question were so large as the Mohawk and Hudson, and with the high "Cohoes" falls on the route.

Prof. Sedgwick gives an instance of similar carriage by the Merrimac River:

TYPHOID INFECTION CARRIED TWENTY-FIVE MILES BY RIVER

	Cases Reported.			Deaths.		
	Lowell.	Lawrence.	Newb'pt.	Lowell.	Lawrence.	Newb'pt.
November, 1892.....	19	14	0	3	4	0
December, 1892.....	70	32	4	10	9	1
January, 1893.....	38	72	28	10	3	3
February, 1893.....	14	23	9	7	12	0
March, 1893.....	.....	.....	.....	4	4	1

—*From Mass. Reports*, 1892.

* Fischer, "Das Wasser," 268.

"In the eight months preceding August, 1892, two cases of typhoid were reported in Newburyport, in the subsequent five there were ten; twenty-eight cases in January, 1893, were thus very unusual. These cases appeared in the same month, but earlier than the increase in Lawrence; they were therefore due to infection from Lowell, more than twenty-five miles distant. The people had warning of the danger from Lawrence."

Professor Williams told the writer that in the summer of 1892 a serious epidemic occurred in Detroit, so that the typhoid death-rate in that year was exceeded by that of only four American cities. The cause was finally traced to Port Huron, sixty miles north. The sewers of Port Huron discharged into Black River, a sluggish stream with very little flow. In the spring of 1892 work was begun by the government upon the dredging of Black River to improve it for navigation, and deposits of foul material from the years' accumulation of sewage in the stagnant reaches were removed by dredging, some of these deposits being eight to twelve feet in depth. This material was taken away in scows and dumped into the swift current of the St. Clair River. Allowing for the time necessary for the water thus polluted to reach Detroit and for the period of incubation of the typhoid germ, the course of the fever in Detroit exactly coincided with the dredging of the polluted material and its deposit in the river, sixty miles above.

In their sixth report (page 138) the Rivers Pollution Commissioners of Great Britain said: "We are led to the inevitable conclusion that the oxidation of the organic matter in sewage proceeds with extreme slowness even when the sewage is mixed with a large volume of unpolluted water, and that it is impossible to say how far such water must flow before the sewage matter becomes thoroughly oxidized."

The inference contained in this old report is not entirely in accord with modern experience. We no longer look entirely to the chemical examination of our information, and we recognize other elements of harmfulness than merely dead organic waste material, and other means of oxidation than direct atmospheric action; but we believe, as they did, that self-purification

of streams is a process not to be implicitly relied on, and that simple dilution enters largely into the safety factor of those who drink water from a polluted river.

When the question of the self-purification of streams first came to the fore, Pettenkofer's theory held undoubted sway, and short distances of river-flow were considered entirely adequate to the removal of gross pollution. Later on the development of bacteriology threw discredit upon this view, and it was held that a water once seriously polluted could never again be safely turned to domestic use unless artificially purified.

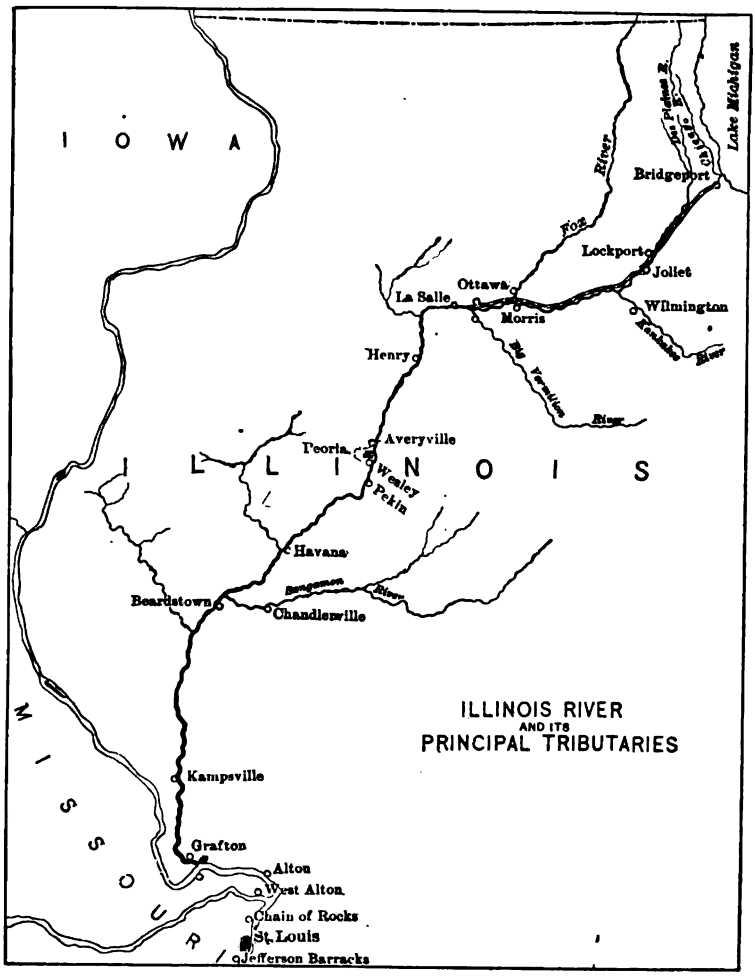
The investigations connected with "The Chicago Drainage Canal Case" in the Supreme Court of the United States, dealing with the alleged pollution of the Illinois and Mississippi Rivers by the opening of the Chicago drainage-canal have tended to again modify our views, and have caused us to admit that practical stream-purification is a fact provided the length of flow be sufficiently great. The distance from Chicago to St. Louis by water is 357 miles, and concerning the situation at the latter place the opinion of the court was that Chicago was not at fault so far as the production of typhoid fever in St. Louis was concerned. In other words, the Illinois and Mississippi Rivers sufficiently dispose of Chicago's sewage by natural means during the above-mentioned length of run.

The record in that case was exceedingly lengthy and even the abstract and summation of it made a large volume; some few points, however, may not be out of place here.

With reference to the widely quoted "*Bacillus Prodigiosus* experiment," wherein 107 forty-gallon barrels of a culture of the bacillus containing from 500 to 1000 million bacilli per cubic centimetre were emptied into the Chicago Drainage Canal, and the organism afterwards sought for at the St. Louis intake; the opinion given was, that in view of the enormous number of the bacilli introduced and the small number (5) found, the result of the experiment show a very considerable death-rate among the germs employed in the test and that, by inference, at least as large a death-rate of the bacilli of typhoid fever,

which they represented, would occur if the latter were exposed to the same conditions.

No little time was devoted to a consideration of the lon-



gevity of the typhoid bacillus; contrasting its power of retaining life for months while in the human body, or while in moist soil, with the shorter duration of vitality when immersed in water; the latter period being measured by days.

Recognition was naturally had of the influence of the

relative purity of the water under consideration upon the result and the tendency of the great density of germ life in polluted waters to inhabit a continuance of the typhoid organism. The view was held that in a relatively pure water its chance for life is greater than in one where it has to fight for existence amid saprophytic bacteria, and the question of the longevity of the germ in water was met by the statement that it dies out therein more or less quickly en masse, although some individual cells, being more resistant, may remain alive for a longer period.

When contrasting the different results obtained while operating upon the experimental scale, using the glass containers common to the laboratory, and comparing them with those secured under conditions more nearly approaching what are found in nature, reference was made to the experiments conducted by the Mass. Board of Health (1902, page 259) touching upon the longevity of the *Bacillus Coli communis*. The vessel employed by the Board of Health was a large tank twelve feet deep. Under those circumstances the life of the bacillus in Merrimac river-water was found limited to eleven days. By inference the typhoid bacillus would not have lasted so long. In other words, as we approach the conditions found in nature the opportunities for the destruction of the pathogenic organism seem to be greater than in those obtaining during during a laboratory experiment.

Dilution as a means of purification was considered and the claim was advanced that although no destruction of organisms can be expected, yet the risk incurred by the man who consumes a pint of water at a draught is certainly diminished through dilution by reason of the fixed number of germs being distributed throughout an increased bulk of water. To the extent therefore that "purification" can be interpreted as a lessening of the degree of danger, to that extent dilution is equivalent to partial purification.

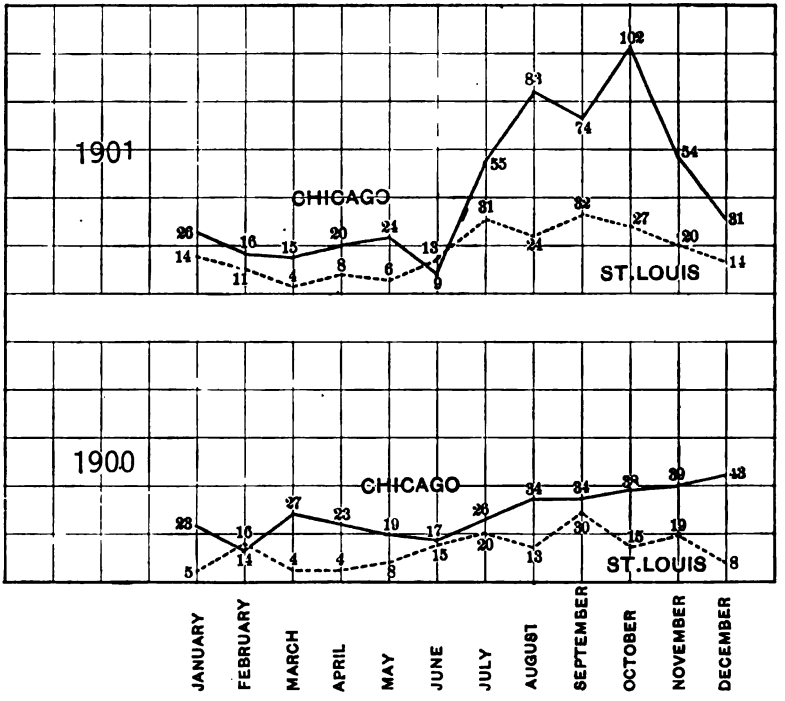
A point upon which stress was laid was the possibility of typhoid organisms accumulating in the mud of rivers by sedimenting from up-stream sources, after a sort of "placer"

fashion, and later becoming "scoured" out during times of flood to the damage of the populations below. As typhoid bacilli will live a long time in moist soil it was asked if a similar vitality were not to be expected in the sludge of river bottoms? There are British statements made which answer this inquiry in the affirmative, but they do not appear to be supported by experimental evidence. On the other hand, the Massachusetts Board of Health experiment already quoted showed the absence of the Colon bacillus from the sediment collected at the bottom of the tank, the examination having been made after an interval of fifteen days.

Should accumulations of virulent germs collect upon river bottoms from up-stream sources and then later be washed out by floods, widespread disease would follow throughout the sections below, yet upon inquiry we do not find recorded as close a relationship between floods and epidemic typhoid as we should reasonably expect under such assumption. The Detroit typhoid following dredging at Port Huron, already referred to on page 229), would seem evidence in support of the "placer" theory; but if that theory were founded upon a general truth there would be many more like instances of down-stream disease resulting from the scouring of stream-bottom deposits. It is easy to understand an increase of typhoid following the rise of a stream like the Tees in northern England, but in that case the accumulations of filth which were swept seaward by the swollen river were not the result of sedimentation, but consisted of night soil and other matters that had gathered upon the dry and rocky foreshores during periods of drought. Such a case is scarcely comparable with the gradual accumulation of river mud, for we know that typhoid germs will live for long periods of time in fecal deposits. In soil the water exists as "moisture" only, while in river sludge it is present in quantity, and opportunity is thereby given for the solution and adverse action of the toxins of antagonistic organisms. This view was, the author believes, first advanced by Jordan, who backed it by experimental support, yet in stating it the fact should not be forgotten that Sedgwick in 1893 succeeded in growing typhoid bacilli in filtered

sewage which contained no germ life of any kind but was presumably rich in saprophytic toxins.

In an effort to show the connection, if any, between the prevalence of typhoid fever in the two cities of Chicago and St. Louis, the following charts were constructed exhibiting



DEATHS FROM TYPHOID FEVER AS REPORTED IN CHICAGO AND ST. LOUIS OFFICIAL HEALTH REPORTS. DEATHS IN ST. LOUIS ARE PLOTTED ONE MONTH IN ADVANCE, I.E., FEBRUARY DEATHS ARE PLOTTED AS OF JANUARY. (THE DRAINAGE CANAL WAS OPENED IN JANUARY, 1901.)

the deaths from the disease by months. The deaths in St. Louis are plotted one month in advance; thus the February numbers for St. Louis are made to correspond with the January readings for Chicago in order to allow for the time consumed by the bacillus in making the journey by water between the two cities, and for the further time required to develop a fatal result after the bacillus had been swallowed. To the author's

mind there is a lack of parallelism between the curves as shown, nor is the case bettered by increasing the time allowance above noted to beyond one month, all of which does not point toward Chicago typhoid having been causative of that found in St. Louis.

The writer sought to lay stress upon the importance of the element of " time " in the self-purification of water, and to call attention to the greater probability of St. Louis importing its typhoid from points of pollution nearer at hand than Chicago. In support of this view data were offered which were later embodied in a paper before the New England Water Works Association entitled " Relation of Intensity of Typhoid Fever to Character of Water Carriage " (Vol. 19, page. 412). Space does not here permit of extended reference to that paper. Suffice it to say that in a mixed epidemic which the writer had opportunity to study (i.e., an epidemic caused by infected water from two sources) it was found that 27.8 per cent of the typhoid cases were severe in type where the disease was traced to a distant origin, while 56.5 per cent was severe when the fever was caused by water from a local source. It would appear from this that support is given to the general proposition that the danger of illness and death will vary inversely as the length of time elapsing between the entrance of polluting material and the drinking of the water. Or, stated in other words, the typhoid bacillus, under prolonged struggle for existence, will lose some of the vigor of its life and will become incapable of producing its normal amount of poison. Under such circumstances either no intoxication results or else a mild type of disease develops among those expecially susceptible to invasion.

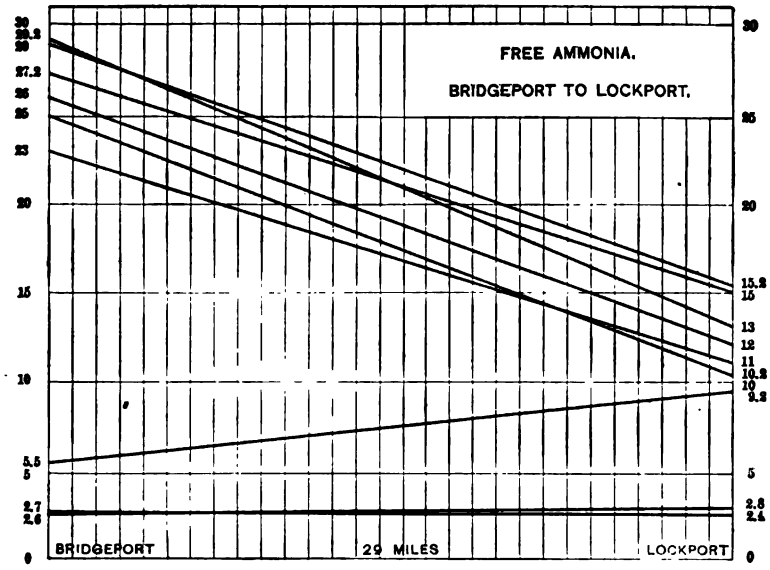
However much we are inclined to accept the Chicago Drainage Canal data as an addition to our knowledge concerning the changes induced by river-flow, one cannot but feel that no upsetting blow has been given to the general proposition that specific infection may cover long distances by water-carriage, and that it would be very rash to prophesy for any particular case just what the limits of such carriage would be until after thorough investigation had been made.

As dealing alone with the chemical changes occurring in polluted water during stream-flow, a former investigation conducted by Professor Long is well worthy of attention. He instituted a series of analyses of the dilute sewage contained in the Illinois and Michigan Canal. It is to be noted that this canal received its supply of water (or rather dilute sewage) at Bridgeport, where the pumps delivered to it the filthy water of the Chicago River, contaminated with a great portion of the sewage of Chicago. From Bridgeport the water "flows along the level to Lockport, twenty-nine miles below, requiring about a day for its passage." It received no dilution on the way and was frequently agitated by passing boats. "After passing Lockport the water descends to Joliet through four locks, and falls over a dam seven feet in height to a point of collection. There is a fall of 58.2 feet in a distance of four miles, and no dilution takes place on the way." The examinations of this canal-water were both numerous and thorough, and judging from the mean results there is good ground for the statement that very considerable self-purification of a chemical character took place during the flow of thirty-three miles.

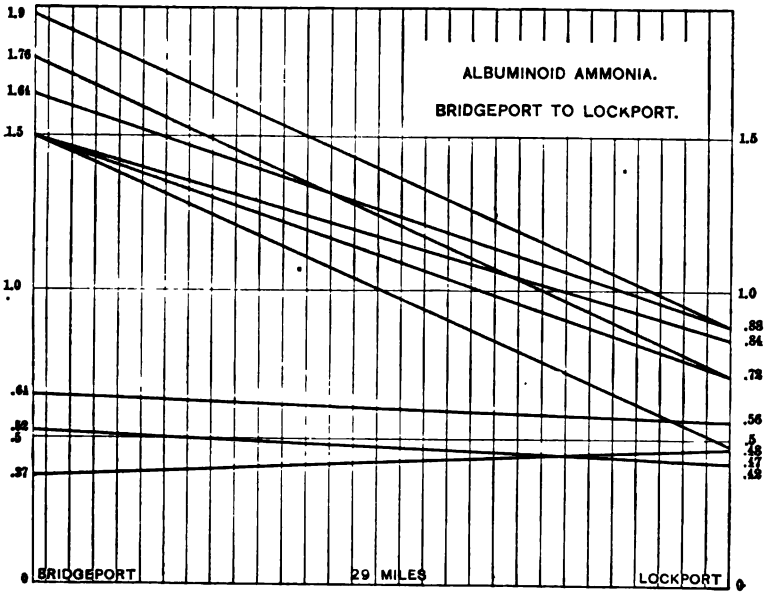
The writer has long been of the opinion that what may be true for dilute sewage does not hold good as we approach the limit of potable water.

In other words, so far as the improving of a water by the natural processes of oxidation is concerned, the rate of such improvement varies directly as the amount of sewage contamination. Given a stream with a certain amount of pollution, the per cent of such pollution which disappears per mile of flow will continually decrease as the stream flows on.

Plotting Dr. Long's figures in graphic form they assume the shape shown on the following charts. The change in lake-level at various dates, together with other disturbing influences, caused comparatively clean water to reach the pumps at times, and we therefore are furnished with data governing the purification of several variously contaminated waters while flowing under constant conditions.



SELF-PURIFICATION IN ILLINOIS AND MICHIGAN CANAL.

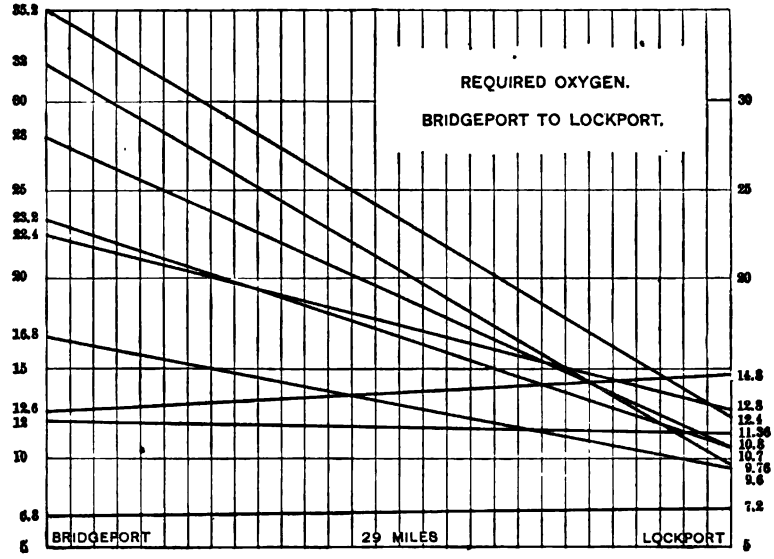


SELF-PURIFICATION IN ILLINOIS AND MICHIGAN CANAL.

It will be noticed that the rate of purification per mile for the more grossly contaminated samples is much greater than that for those comparatively pure.

Even the best of these waters of the Illinois and Michigan Canal was very far from being potable, and we may consequently look for still further reduction in the purification rate as we near the potable limit.

We have seen that the amount of oxygen dissolved in a



SELF-PURIFICATION IN ILLINOIS AND MICHIGAN CANAL.

water need not be large in order to permit the purification changes inaugurated by nature to go on; but in the event of the supply of oxygen being entirely cut off, putrefactive reactions are set up with very undesirable results.

A case of this kind is reported by Dr. Leeds as occurring during the winter of 1882–3. The exceedingly bad taste and smell of the Philadelphia water was found by him to have been due to a superabundance of putrescible material, at a time

when the dissolved oxygen was unusually small in quantity. The rainfall of the late autumn and early winter had been very slight, thus producing a low state of the river. Polluted water in extraordinary quantity had been admitted by the emptying of sundry dams and canal levels, and the atmosphere was cut off from direct action upon the river by a continuous coating of ice. Under these circumstances the foul-smelling compounds well known to form when organic matter decomposes out of contact with air were produced in large quantity, to the great discomfort of the water-consumers. So considerable in amount were the gaseous products in this instance that it was possible to ignite them as they escaped from holes in the ice. The flame produced by igniting the gas issuing from a penknife puncture of the white hollows under the ice is described as being usually six inches high, but once it was "fully a yard high." *

A curious instance of similar character was reported in the Chicago papers of November 2, 1894, Refuse matter had accumulated in so great quantities in the Chicago River that the available oxygen was far too small in quantity for its proper oxidation. Gaseous and inflammable products of sub-aqueous putrefaction resulted, which upon ignition at the surface became almost dangerous to shipping. "The tug A. Mosher was towing the schooner Ford River out of the South Fork, when both boats were surrounded by the fire, which was consuming the gases rising to the surface in huge bubbles."

Judged from the bacteriological standpoint, a considerable monthly and seasonal variation will be observed in the purity of running streams. During the low water of summer, although the relative volume of sewage-inflow is large, yet the absence of surface-washings, due to storms or melting snow, usually causes diminution in the total number of bacteria present;

* J. Frank. Inst., lxxxvi. 26.

for instance, Percy Frankland gives the following counts of bacteria per cubic centimetre in Thames water collected at Hampton:

January	92,000
February	40,000
March	66,000
April	13,000
May	1,900
June	3,500
July	1,070
August	3,000
September	1,740
October	1,130
November	11,700
December	10,600

Jordan was the first to point out that improvement of a chemical type and of a bacterial character, during the flow of a stream, do not follow parallel courses.

Objectionable bacteria may die out during a run shorter than that required to oxidize non-living organic matter.

The seasonal variation in total count of bacteria is also partly due to the greater number of enemies the bacteria have to face during the warmer months. Both plants and animals which limit their growth are plenty in summer and relatively few in winter, when the water is covered by ice. There are many " bacteria-eaters," such as the large family of " Rotifers " or " Wheel animals," which in turn are eaten by animals of larger growth.

Dr. Ruediger, Director of the State Public Health Laboratory, University of North Dakota, Grand Forks, N. Dak., prepared a table showing variation of number of *B. coli* per centimetre in the water of Red Lake River with the change of season; the figures are averages of four analyses of samples collected at intervals of six hours:

Date.	B. Coli, per c.c.	Volume of Water in River: Cu.ft. per Sec.	Calculated B. coli per c.c. if Volume of Water Always = 750 Cu.ft.
River	Not Covered	with Ice.	
June 18, 1909	2⅛	1120	3.0
July 12, 1909	3½	782	3.5
Sept. 11, 1909	6¼	1000	7.3
June 4, 1910	2	1180	3.3
June 28, 1910	5½	750	5.5
Aug. 15, 1910	6	300	2.0
River Covered with	Ice (average	thickness 30	ins.)
Jan. 18, 1910	15½	770	15.5
Mar. 1, 1910	17⅛	610	14.0

A long, full article will be found in *Engineering News*, August 31, 1911 on "The Significance of Flora and Fauna in Maintaining the Purity of Natural Waters, and How they are affected by Domestic Sewage and Industrial Wastes." * Translated from the German by Emil Kuichling.

At times it chances that some substance of especially marked smell or taste becomes mingled with the general mass of sewage contaminating a water, and a lively sense of pollution immediately takes possession of the consumers. For instance, some years since, a paper-mill dumped refuse containing a little carbolic acid, into a tributary of the Passaic River, at a point above the common intake of the cities of Newark and Jersey City. So strong was the odor and taste communicated to the supplies of the two cities that use of the water for drinking purposes was for a time discontinued. The quantity of carbolic acid consumed by each individual using the water was well-nigh infinitesimal and beyond possibility of doing harm, yet serious objection was made to the "pollution" of a stream which was already laden with the sewage of fifty thousand persons residing at the city of Paterson, only eighteen miles above.

Again: The city of Cleveland, O., takes its Lake Erie water

* See also Whipple's "Microscopy of Water" for influence of higher fish life.

from an intake situated beyond the breakwater, and the city sewage passes into the artificial harbor and thence is delivered into the lake at a point well down the east shore. It might be thought that there was little chance of sewage working so far westward against the general trend of current, but it so happens that oily material from the Standard Oil Company's works constitutes a portion of the city sewage, and it has been noticed that a petroleum taste is given the water when the direction of the wind causes an accumulation of sewage in the harbor, which sewage is afterwards permitted to rapidly escape into the lake upon change in the weather. In each of these cases the special material was but a harmless indicator of the presence of the unrecognized but far more dangerous sewage pollution, yet the public strongly objected to the one and calmly accepted the constant presence of the other.

It will be remembered that some years ago, about 1879, a portion of Boston's water supply was considered in great danger of contamination with sulphuric acid, owing to the burning of chemical works situated upon one of the tributaries to Mystic Pond, whereby some fifty tons of oil of vitrol were washed into the stream. Mystic Pond is about eight miles below the site of the works, and mill-ponds intervene. Marked acidity was noticed at varying points in the course of the stream and intervening ponds, but no trace of acid remained by the time Mystic Pond itself was reached.

This instance has been often dwelt upon to show how nature may take care of even the stable inorganic additions to surface-waters.

CHAPTER V

RAIN, ICE AND SNOW

SAUSSURE held that a part of the water raised into the atmosphere resembles soap-bubbles.

Clouds he considered to be composed of small vesicles, of which water formed the envelope. And he further believed that every vesicle that rises from the sea must contain a small quantity of the solid matter which was dissolved in the sea-water; the proportion of solid matter taken up in a given space varying according to the relative proportions of these original vesicles that enter into the composition of the clouds.*

The more modern view is stated by Douglas Archibald: †

"Rain is the final stage of condensation of vapor back into water, of which cloud is a half-way stage. The mist which composes a cloud is formed of tiny drops of water about $\frac{1}{3000}$ inch in diameter. It used to be a puzzle to explain how these water-particles were sustained, and it was at one time supposed that cloud-particles were hollow. We know now that this is neither necessary nor true, since very small particles, even of gold, will remain suspended for a long time in air; the finer the particles the longer they take to fall. A slight upward motion of the air is therefore enough to keep them balanced. As condensation proceeds these particles grow larger by fresh coatings of water, and the larger ones fall down against the smaller and mingle with them until large drops from $\frac{1}{200}$ to $\frac{1}{100}$ inch thick form, which are no longer capable of being suspended and fall to the earth. Snow forms when the temperature at which this further stage of condensation occurs is below freezing-point.

* Angus Smith, "Air and Rain," p. 233.

† "The Story of the Atmosphere."

"Hail is frozen water-drops. It is believed that the raindrops formed in one part of a storm are carried upward by powerful ascending currents (twenty-five miles an hour is enough to sustain large drops) into higher regions of the atmosphere where they are solidified by the excessive cold, and being carried over with the overflow which takes place near the top, fall down until they are redrawn into the interior of the storm and again whirled up aloft. Receiving alternate meltings and freezings, and growing larger with each circuit they make in the atmospheric churn, they are finally thrown out on either side of the storm-centre. This explains the fact that in a traveling hailstorm there are two bands where hail falls on either side, while under the center it is often found that only rain has fallen."

Hailstones of great size occasionally occur; thus on June 23, 1906, a violent hail-storm swept over Staten Island, N. Y., during which hailstones fell measuring nine inches in circumference.*

The presence of solid matter in rain-water is accounted for by the large quantities of dust of all kinds continually carried into the atmosphere by the winds, and washed therefrom by the falling drops. In the vicinity of large towns various products of incomplete combustion and of industrial waste are added to the atmospheric impurities, and are precipitated along with the more commonly occurring dust; † while in the vicinity of the sea the amount of common salt present increases materially.

The presence of soot in the air causes increase in the rain-water of such impurities as sulphuric acid and ammonia, by what appears to be direct absorption of such material by the soot. This is shown by Mabery in the following analysis of the air of Cleveland, Ohio: ‡

* Science, July 23, 1906.

† The English Alkali Act permits the presence of HCl to the limit of 0.2 grains, and of SO_3 to the limit of 4 grains in each cubic foot of air, taken at the foot of the stack of such industrial plants as generate these waste products.

‡ J. Am. Chem. Soc., xvii. 3.

WEIGHT IN MILLIGRAMMES PER LITRE OF AIR

Soot.	Sulphuric Acid.	Ammonia.
87.5	15.2	.070
45.2	6.3	.010
111.3	21.2	.120
41.8	13.9	.003

On September 8, 1894, there occurred the first rain, after the longest period of drought that had been experienced in the State of New York during forty years. Many forest fires had occurred and the atmosphere had been exceedingly hazy for weeks.

The author collected rain-water, on the above date, in the Catskill Mountains, and the quantity of oily, sooty material it contained was very striking.

The amount of this soot from the air may be very great, thus Kershaw found * as much as 25 tons per square mile per year in a country district in England and up to 539 tons per square mile per year in a manufacturing town.

Baskerville and Weller give the analysis of a "black rain" colored by soot which fell at Louisburg, N. C., in March, 1900.†

A red rain, whose color was produced by dust of possibly a cosmic origin, fell upon a number of places in central and southern Europe between March 11 and 13, 1901. Other abnormal precipitations such as salt rain, rain colored by volcanic ash or by desert sand, and the "bloody snow" produced by growths of *Palmella sanguinea*, have been mentioned by Phipson in his "Researches on the Earth's Atmosphere." ‡ Averages for many years, showing amounts of ammonia and nitric nitrogen carried down by rain at Paris and in different parts of England, may be found in the Report of the Montsouris Observatory for 1897.

* Surveyor, 43:462.
† Science xv, 1034.
‡ See also Chemical News, lxxxiii. 159.

The various germs floating in the air, and ready to be carried down by the first shower, do not play a material *rôle* from the water-supply standpoint, partly because of the improbability of their being pathogenic in character, and partly because of the germicidal power of the direct sunlight to which they have been so thoroughly exposed.

Nevertheless it may be of passing interest to give the official figures issued by the Montsouris Observatory, Paris:

BACTERIA PER CUBIC METRE OF AIR AT MONTSOURIS

(Average for ten years)

January	160
February	145
March	225
April	310
May	305
June	355
July	465
August	455
September	310
October	190
November	195
December	165
Mean	275

A comparison of country and city air shows the following number of bacteria per cubic metre:

Montsouris	275
Center of Paris	6040

There is a daily maximum of bacteria at 2 P.M. and a minimum at 2 A.M.

It may be worth adding that Miquel gives the following comparison, in terms of bacteria per cubic metre, between the air of the Paris sewers and that of the public streets:

	Air of the Sewers.		Air of the Streets.	
	Bacteria.	Molds.	Bacteria.	Molds.
Winter	2385	4050	3,210	599
Spring	7165	2330	11,085	865
Summer	5110	2730	12,070	2340
Autumn	5400	1550	7,365	2320
Mean	5015	2665	8,435	1530

The monthly variation in the chlorine contained in rain-water collected at Troy, N. Y., is given in the following table, the determination having been made in a mixture of the entire rainfall for each month:

January	2.50 per million
February	1.07 "
March	1.55 "
April	0.75 "
May	1.25 "
June	1.15 "
July	1.05 "
August	2.00 "
September	0.60 "
October	3.00 "
November	2.25 "
December	2.50 "
Mean	1.64 per million

Even casual inspection will often show that rain-water is a long way from being pure, and, high as this "water from the heavens" is rated in the public mind, it is frequently polluted to an extent quite surprising to the collector of the supply.

The author has often noted the confidence with which people will make use of water from a foul cistern, even when the odor of the water is strongly objectionable, because of their entire faith in the purity of the original source.

Thus water from a dirty cistern in West Troy showed the following analysis. In appearance the water was good.

Free ammonia	1.050 per million
Albuminoid ammonia	.175 "
Chlorine	2.000 "
Nitrogen as nitrites	strong trace
Nitrogen as nitrates	0.0 per million
Required oxygen	2.25 "
Total residue	20.00 "

The roof upon which rain is caught is a twofold cause of impurity in the collected water; first, because of the material of which the roof is constructed, and, second, because of the foreign substances that may settle thereupon.

In cities the amount of street-dust blown upon the roof and afterwards washed into the cistern is much greater than is commonly supposed. Soot, excrement of birds (often a large item), fallen leaves, horse manure, and various mossy growths are among the sundry additions to be found in a roof-collected water.

A question of the first importance in considering a rain-water supply is the material out of which the walls of the storage-cistern are to be made. Slate and stoneware naturally suggest themselves as the most suitable materials, but they are not always available, especially if the cistern be a large one Cement linings, particularly for underground structures, are by far the most common, and the objection that the lime in them may somewhat increase the hardness of the water is not of much weight, in view of their convenience and low cost.

Tanks of wood serve their purpose well, provided they be kept full; but if there be great fluctuation in the water-line, organic development is liable to occur, and the tank itself falls out of repair. The city of New Orleans formerly possessed many tanks of cypress-wood.

Cisterns of metal are open to a number of objections. Iron rusts and colors the water; lead is dissolved by rain-water very energetically, and is consequently highly objectionable; zinc is attacked, and so also is galvanized iron. Tin would be a

suitable metal, but pure tin would be too expensive, and "tin-plate" is often defective and is open to rust.

When the controlling circumstances demand a metallic-lined cistern, the metal chosen should be thoroughly coated with a good asphaltum paint, or else heavily tinned copper should be used.

The commonly employed delivery-pipe which dips into, and remains in permanent contact with, the water of the cistern, should also be coated within and without like the cistern walls.

It is exceedingly important that every cistern should be inspected and cleaned frequently, and upon no point does the public require more instruction than this.

One form of underground cistern which has been very widely favored in the past is that belonging to the "filtering" type. It is constructed by simply dividing the cistern into two chambers by a vertical brick wall. Water enters one of these divisions and is drawn from the other after percolation through the dividing wall. Such an arrangement cannot be too strongly condemned. The wall is a mere strainer at the best; it cannot be properly cleaned, and it gives a false sense of security.

The suitable location of an underground cistern is a matter that one might think could be safely left to the good sense of the average householder; but such is far from being the fact. The writer examined one case in which, on account of a defective lining and a leaky sewer, a portion of the house-drainage was returned to the house along with the cistern-water and used for household purposes. In another instance an unlined cesspool was observed located in a bank ten feet *above* and fifteen feet to the west of the well furnishing the family's supply of water.

Wherever the cistern is located it should be protected from mosquitoes, by screening if necessary. The wooden roof-tanks so often seen on buildings supply excellent breeding places for these pests.

While its softness recommends it for use in the laundry,

and while the absence of lime-salts renders it desirable for cooking, rain-water is, on the whole, not to be considered so suitable as a high-grade ground or surface water for general domestic supply.*

Ice, especially in America, is unquestionably to be ranked as an article of food.

Throughout the colder sections of the country "natural ice" controls the market almost completely, and some of the dealers supplying the same "harvest their crop" from the first sheet of water they find conveniently located, without inquiry as to the suitability of its condition, assuming that the process of freezing eliminates all objectionable features that the water may chance to possess. The author has examined ice from ice-houses deriving their supplies from canals, barnyard ponds, and the like—localities from which no one would ever dream of drawing a supply of water.

The law of Massachusetts, enacted in 1886, to prevent the sale of impure ice reads:

"Upon complaint in writing of not less than twenty-five consumers of ice which is cut, sold, and held for sale from any pond or stream in this commonwealth, alleging that said ice is impure and injurious to health, the State Board of Health may appoint a time and place for hearing parties to be affected, and give due notice thereof to such parties, and, after such hearing, said board may make such orders concerning the sale of said ice as in its judgment the public health requires."

In New York the law is:

"No ice shall be cut for domestic, family, hotel, boarding house, restaurant, or other similar use, or for sale for any such use, from any impure or contaminated source upon any waters within this state. No person, firm or corporation shall cut or harvest any ice on any of the waters within this state for any such use without first obtaining from the local board of health having jurisdiction over the waters upon which it is so cut or from the state commissioner of health a written permit.

* For a description of the water supply of Gibraltar see p. 349.

A permit granted by a local board of health may be revoked by such board or by the state commissioner of health. A local board of health or the state commissioner of health may include in such permit such instructions and regulations regarding the manner in which such ice shall be cut and harvested as may be deemed necessary to protect the public health, and the state commissioner of health may by general or special rules prescribe such regulations. A certified copy of any permit issued by a local board of health shall immediately after its issue be filed by such local board of health in the office of the state commissioner of health, and such permit shall not be effective until so filed. No ice cut from any impure or contaminated source or dangerous to health shall be sold or offered for sale for any domestic, family, hotel, boarding house, restaurant, or other similar use. The state commissioner of health is hereby authorized to make such rules and regulations and the said commissioner and local boards of health are authorized to make such inspections as may be necessary to enforce the provisions of this section. Any person who cuts, harvests, sells, or offers to sell, or stores or transports with intent to sell, any ice contrary to the provisions of this section shall be liable to a penalty not exceeding five hundred dollars. Each day that ice is cut contrary to the provisions of this section shall constitute a separate offense.

Reference has already been made to the small quantity of purification to be expected from the freezing of water when judged by chemical standards: and Dr. Prudden has shown how imperfect the result is when viewed as a bacteriological question*.

He found alternate freezing and thawing more fatal to bacterial life than a more prolonged period of continuous freezing.

The prevalent belief that water completely purifies itself during the act of freezing is so well fixed in the public mind that the source whence ice is harvested is in consequence usually

* Medical Record, March 26, 1887.

considered unimportant. This belief is not without some support in fact, but like many another partial truth it is a very uncertain foundation upon which to erect the best form of sanitary procedure.

A cake of ice in forming thickens by additions to its bottom; in other words, it grows downwards. As the crystals enlarge they tend to shove out and away from themselves all forms of foreign matter which may be suspended in the water, thus purifying the ice layer and correspondingly increasing by concentration the pollution of the water below. The amount of such concentration in a river would, of course, be only nominal. Should the ice be formed upon a shallow basin, however, the degree of the concentration might become serious, and if the water should freeze throughout its entire depth all of the impurities present would of necessity be found in the ice and the major part of them would appear in the portion last frozen.

This state of things may be well seen in a cake of artificial ice made from impure water. All the suspended foreign matter will be observed collected at the centre of the cake, where it was driven and finally entangled by the ingrowing crystals which began their formation at the periphery.

Certain experiments were undertaken in this laboratory by Messrs Sherry and Morey upon water containing 64,000 bacteria per cubic centimetre.

When a ten-gallon sample of this water was allowed to freeze solid, stored for three weeks and the ice then sampled from the centre of the cake, where concentration was greatest, such ice was found to contain only 72 bacteria per cubic centimetre, showing a purification efficiency of 99.87 per cent.

In the center of another cake (from water containing 40,000 per cubic centimetre) about one quart of water yet remained unfrozen at the end of a week and this water (containing 4000 per cubic centimetre) exhibited a purification efficiency of only 90 per cent. This latter figure represented the result of a reduction in bacteria due to certain of the freezing conditions and an increase in the count due to concentration. At the end of the second week, the entire cake having meanwhile

frozen solid, the ice of the centre showed 400 bacteria per cubic centimetre, at the end of the third week 140, and at the end of the fifth week 125.

Sparks found that in stored ice "The colon bacilli were reduced in number about 65 per cent in two days, 90 per cent in four, 95 per cent in one week, 99.3 per cent in two weeks, and 99.99 per cent in nine weeks, and sterility was found in twelve weeks. Typhoid bacilli were reduced in numbers 72 per cent in two days, 91 per cent in four, 94 per cent in one week, 96 per cent in two weeks, 99.99 per cent in seven weeks, and sterility was found in nine weeks."

According to Sedgwick and Winslow "Less than 1 per cent of the typhoid germs present in water can survive fourteen days of freezing, and that during the first half hour of freezing a heavy reduction takes place amounting to perhaps 50 per cent; after this the reduction proceeds pretty regularly as a function of time." *

Much has been done in the matter of investigating the beneficial effects of the freezing action and valuable data will be found in the Report of the Massachusetts State Board of Health, notably in the volume for 1902, page 271. There is undoubted advantage to be secured by ice storage, and without question the summer supply taken from the ice-houses is safer than that recently cut during the winter

As Sedgwick has aptly said, however, "it is small comfort to the individual suffering from typhoid fever contracted from polluted ice to be told that 99 per cent of his friends use ice with impunity."

Ice-borne epidemics of typhoid are fortunately rare, but not unknown, as is instanced by the outbreak of the fever at the St. Lawrence State Hospital, near Ogdensburg, N. Y.†

It is not an unknown practice, although a very unworthy one, for icemen to quickly build up their "crop" by flooding the thin ice-field with river-water. This is commonly done to wet down a newly fallen layer of snow and thus avoid the

* Am. Acad. Arts and Sci., xii. No. V.

† Am. J. Med. Soc., Oct., 1903.

expense of scraping the ice-field. As a result the cake grows in both directions; but there is no opportunity for natural purification to take place in the upper or flood portion, which part must of necessity freeze as a whole, thus retaining in the ice everything which may have been present in the water.

With reference to the degree of purification taking place upon the under side of the ice-cake, it is, as already stated, a matter of decided importance, but it is nevertheless short of what is claimed for it by most of our people.

As the crystals of ice form they are sure to entangle more or less suspended material, particularly that which is specifically light and which therefore tends to hug the under side of the growing cake.

Hence the fact that melted ice often shows more vegetable debris than the water from which it is formed.

Bacteria, whether of harmful form or not, are minute vegetable entities which, though invisible to the eye, are nevertheless suspended in the water and are subject to the same laws of exclusion or entanglement by the ice-crystals as are the particles of larger and visible size.

So far as damaging the appearance of the ice is concerned, bacteria are of no account whatever, but it is wise to repeat here that no reliance must be placed upon the conditions of ice formation to produce complete removal of the objectionable organisms.

Judging from the results of an investigation by the writer of ice from the upper Hudson district, such removal under large scale commercial conditions, and without allowing for the benefit of storage, would appear to lie between 90 and 95 per cent of all bacteria present in the water.*

This percentage of purification would be increased through the influence of storage, but some of the germs that we are anxious to eliminate might remain among the number retained by the ice.

It seems evident, therefore, that if pathogenic bacteria become frozen into the ice-cake there is possibility that some of

* See page 256.

them may reach the consumer in a living condition, and capable of doing mischief, even though a period of months should elapse between the " harvesting of the crop " and the delivery for consumption.

Of course the ideal rule to follow is never to cut ice from a source whence it would be undesirable to drink the water, but like many other ideals this one presents practical difficulties in the way of its attainment.

In view of the very large imvestment represented by the ice industry it might be unwise and unfair to suddenly impose too severe conditions upon those engaged in the ice business, but it does seem reasonable to insist that the ice furnished the people for use in beverages should be required to show negative results when tested for the presence of the *Bacillus coli communis.*

As concerning the relative merits of transparent and snow ice, Prudden gives the following determination of bacteria per cubic centimetre contained in the two varieties of ice cut from the same cake:

	Bacteria per Cubic Centimetre in the melted ice.
Transparent ice	46
Snow-ice	10,020
Transparent ice	3,192
Snow-ice	15,624
Transparent ice	2,322
Snow-ice	55,062
Transparent ice	218
Snow-ice	9690
Transparent ice	918
Bubbly-streak ice	26,049

The white ice is richer in bacteria, because it contains large quantities of air, and therefore is capable of more readily supporting the aerobic varieties. It is also exposed to the impurities likely to be introduced by the " flooding " practice already alluded to. The bacteria have not been excluded during freezing.

ANALYTICAL RESULTS OF A CHEMICAL AND BACTERIOLOGICAL EXAMINATION OF SAMPLES OF ICE AND THE WATER FROM WHICH IT WAS FROZEN. (PART OF REPORT SUBMITTED TO MANUFACTURERS' ASSOCIATION OF NEW YORK.)

Derivation of Samples. Remarks. Results in parts per million.	Date, 1901.	Sample.	Color, Platinum Scale.	Sediment, Quickly Falling.	Turbidity, per Clay Standard.	Free Ammonia.	Albuminoid Ammonia.	Chlorine in Chlorides.	Nitrogen in Nitrates.	Nitrogen in Nitrites.	Oxygen required to Oxidize Organic Matter at 212° F.	Alkalinity (as parts of $CaCO_3$)	Total Solids.	Bacteria per Cubic Centimetre.	Bacillus coli communis.
From Ice-house 18, Map 1, Mohawk Basin. Taken from ice-field during harvesting. Water about nine feet deep.....	Feb. 19	Water	.15	Slight	4	.277	.103	5.5	.332	.005	7.95	52.5	152	450	Present
This ice was fifteen inches thick and was clear.		Ice	None	Slight	None	.041	.093	1.5	Trace	None	.8	None	13	40	None
From Ice-house 21, Map 1, Mohawk Basin. Taken from ice-field during harvesting. Water about twenty feet deep.	Feb. 21	Water	.15	None	4	.282	.098	6.5	.5	.006	8.07	50.	180	1,440	Present
The melted ice was, in appearance, inferior to the water. It contained considerable floating vegetable debris.		Ice	Trace	See Remarks	4	.095	.023	1.	Trace	.001	1.8	None	5	150	None
From Ice-house 11, Map 1, Upper Hudson, above Mohawk Junction (middle of river). Water eight feet deep.	March 1	Water	.3	None	15	.047	.067	1.	.15	.0005	31.3	25.	118	2,100	Present
The ice was twelve inches thick and much superior in appearance to the water when melted.		Ice	None	Marked	18	.158	.135	.75	Trace	Trace	5.3	None	103	42	None
From Ice house 16, Map 1, Hudson River just above State dam. Water was 13 feet deep.	March 5	Water	.25	None	18	.168	.135	2.	.219	.0015	17.	35.	139	4,860	Present
The ice was ten inches thick, clear, and very fine in appearance.		Ice	None	None	2	.04	.069	1.	.019	None	1.2	None	20	70	None
From Ice-house 23, Map 1, Back channel of Hudson River, below Troy. Water five feet deep.	Feb. 27	Water	None	None	18	.327	.448	10.	.875	.02	10.	62.5	247	91,000	Present
		Ice		Considerable	20	.282	.258	3.5	.112	.002	5.9	None	128	120	None
From midway between Ice-houses 4 and 5, Map 2, below Lower Bridge, Albany. Location exposed to Albany sewage.	Feb. 22	Water	.3	Slight	6	.125	.147	5.	.25	.002	16.	35.	149	5,360	Present
		Ice	None	Slight	4	.081	.034	1.25	.125	.001	2.	None	24	570	Present
From Erie Canal near Ice-house 15, Map 1, used to fill ice-pond.	Feb. 25	Water	.15	None	6	.298	.102	6.	.4	.007	6.8	52 5	188	2,000	Present
Appearance of melted ice inferior to the water		Ice	None	Considerable	25	.138	.098	1.75	...	None	2.6	None	75	60	None

The slower the formation of ice, and the deeper the water on which it forms, the better will be its quality, other things being equal. The rate of formation decreases as the ice thickens, hence it follows that the lower portion of a thick layer is purer than the upper.

At 14° F. ice forms at following rate: *

1	inch in	2.06	hours
6	"	1.95	days
10	"	5.19	"
1	foot in	7.38	"
2	"	28.60	"
3	"	63.69	"

It may not be out of place to interject here the following *army rules relating to the strength of ice.*

Two-inch ice will sustain a man or properly spaced infantry; four-inch ice will carry a man on horseback or cavalry or light guns; six-inch ice, heavy field guns, such as 80-pounders; eight-inch ice, a battery of artillery with carriages and horses, but not over 1000 pounds per square foot on sledges; and ten-inch ice sustains an army or an innumerable multitude. On fifteen-inch ice railroad-tracks are often laid for months, and ice two feet thick withstood the impact of a loaded passenger-car after a sixty-foot fall (or perhaps 1500 foot-tons), but broke under that of the locomotive and tender (or perhaps 3000 foot-tons).

Quarrying ice from the Swiss glaciers has been practiced upon a commercial scale, the ice having been broken out by blasting.

Ice in very notable quantity occurs in various parts of the world in the so-called "ice-caves" or "glaciers." These caves are sometimes of considerable size. Thus, according to Balch, the cave at Dobsina, in the Carpathians, is about 10 metres high, 120 metres long, and some 40 metres broad.

"The stalactites form grand ice-pillars. They are from

* See Barnes, "*Ice Formation*," page 103.

8 to 11 metres in height, and from 2 to 3 metres in diameter. In some of the caves, as at Chaux-les-Passavant, the ice stalagmites take nearly the form of cones. There are some seven or eight of them, the tallest of which is at least 6 metres high with a diameter at the bottom of 5 to 6 metres. Sometimes these cones are hollow, as is the case in a grand one at the Schafloch, some 6 metres or more in height."

"This great cave was entirely cleared of its ice in 1727 by the Duc de Levi for the use of the Army of the Saone. In 1743 the ice was formed again. At Szilize, every year, the ice has almost completely disappeared by November, and the cave is free; but in April or May the floor is again covered with ice, and columns and icicles have formed on the roof and sides. At La Genolliere the cave is used by the people of the neighboring chalets through the spring and early summer to help in the operation of butter-making."

Cave ice is built up from the freezing of percolating water.

"It is formed entirely by the cold of winter; the heat of summer tends to melt it. Owing to the sheltered position of cave ice the summer heat reaches it with more difficulty than it reaches the snow and ice in the open, and it therefore remains long after the ice in the surrounding country has disappeared."

Anchor ice, while not a source of supply, may deserve a word here for the reason that it not uncommonly becomes troublesome by blocking up the entrances of water-works intakes.

Heat radiation from submerged surfaces, especially those of dark color, will in higher latitudes often allow of ice formation beneath the water-level, as upon the intake strainers, and this ice once started may be greatly added to by accumulated masses of "needle" or "frazil" ice mechanically carried down by descending water currents, and then frozen to the anchor ice proper. Cold, clear nights are favorable to these formations. During the day masses of this submerged ice will occasionally loosen and rise to the water-surface, but that portion which is attached to the irregularities of the intake-screen

is hard to detach. Steam and warm air have been used for its removal but such a remedy is expensive and may not be available in remote localities. An electric current through the strainer bars has been used with good results. A simple device for avoiding anchor ice formation, one which is always worth trying but which is not uniformly successful, is to build a raft or platform over the site to be protected; the object being to prevent radiation of heat from the surfaces beneath. Of course a covering of sheet ice would serve the same purpose. It is claimed that anchor ice does not form at depths below forty feet. It has never troubled the intakes of Toronto or Milwaukee, which draw from depths of eighty and forty-six feet respectively.

Artificial ice is making very rapid strides toward popularity, and if its manufacturers would confine themselves to the use of thoroughly safe water as a basis for their product, there is no question but that the confidence of the people would be well placed and permanently retained.

Unfortunately, there is a quantity of artificial ice offered for potable use that is made from very ordinary water; and, inasmuch as the usual method of formation causes the water used to freeze as a whole, all the impurities of the water are retained and concentrated in the centre of the cake of ice, that being the last portion to solidify. Unless the water employed be distilled, such artificial ice must, of necessity, be more impure than natural ice frozen from the same water.

The objection advanced above does not, however, apply to a method of preparing ice whereby the processes of nature are closely imitated, the ice being permitted to form on a vertical freezing plate immersed in flowing water.

Snow can be considered only as an indirect source of water supply, but as such it assumes a position of some importance. The water from melted snow (which, according to the U. S. Weather Bureau, averages in depth one-tenth that of the snow before melting) is commonly more impure than rain-

water from the same locality, for the reason that its flakes act better than the spherical rain-drops for entangling impurities suspended in the atmosphere, and their low temperature is conducive to the absorption of ammonia. Analysis of city and country snows from the same general locality show marked differences which are illustrated in the results obtained from samples gathered in the city of Troy, N. Y., and in the near-by open country:

	City Snow. (Troy, N. Y.)	Country Snow. (Menands Station.)
	Parts per million.	Parts per million.
Free ammonia	.460	.15
Albuminoid ammonia	.225	.06
Nitrogen as nitrates	.200	Trace
Nitrogen as nitrites	Trace	Slight trace
Chlorine	1.87	.60
Required oxygen	1.90	1.00

Of course, as is the case with rain, the first portion of the fall must always contain the greatest amount of impurities. The chlorine in city snow (Troy, N. Y.) was thus found to vary during the same storm of two days' duration. (Not the same storm as above.)

First day..... 3.05 parts per million
Second day..... 2.55 " "

London snow was found by Coppock * to contain:

Total solids..... 237.3 per million
Mineral matter..... 89.3 " "
Carbonaceous matter..... 156.5 " "
Free ammonia..... 66.3 " "
Albuminoid ammonia..... 93.0 " "

The first half of the above-referred-to snowfall contained 75 per cent of the impurities. The carbonaceous matter was ordinary soot.

* *Chem. News*, lxxi. 92.

After snow is once upon the ground it changes in composition quite rapidly, particularly in its contained ammonia. This change is, moreover, greatly influenced by the character of the surface upon which it rests.

Thus the tendency of snow to absorb impurities from the soil is shown by the following comparative analysis of samples taken from a roof and from a meadow (results in parts per million):

	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Required Oxygen.	Total Residue.	Loss on Ignition.
Fresh snow from roof..	.50	.15	.80	trace	trace	.50	22.	7.
Same snow after lying on roof two days....	1.24	.21	.85	trace	trace	2.85	64.	21.
Fresh snow from meadow.....	.27	.11	.75	trace	trace	.40	41.	12.
Same snow after lying in meadow two days.	.79	.26	.70	trace	trace	2.70	65.	29.

Additional force is thus given to the saying, "Snow is the poor man's fertilizer," and "The fogs and snow remain to fatten the land."

The great influence that melting snow has upon spring-water is shown by the following analyses of a flow from a spring in Rensselaer County, N. Y. The water serves as an illustration, although it is not a "normal" water, as is seen from the high chlorine.

Results in parts per million.	Oct. 15.	Nov. 10.	Dec. 15.	Jan. 12.	Feb. 5.	Mar. 2.	April 6.	May 8.	June 5.
Free ammonia.....	trace	trace	.015	.010	.025	.027	.025	.01	.01
Albuminoid ammonia.	.036	.03	.055	.035	.090	.078	.060	.04	.07
Nitrogen in nitrites...	.000	.000	.000	.000	trace	.000	.000	.000	.000
Nitrogen in nitrates...	.116	.075	.15	.15	trace	.30	.15	trace	.05
Chlorine.....	20.5	17.3	19.	19.	21.	20.	21.5	18.	17.
"Required oxygen"...	.000	.1	.4	1.15	1.5	1.0	.3	.1	.5
Total solids.....	570.	570.	558.	534.	579.	543.	554.	553.	552.
Loss of ignition.....	.....	79.	62.	44.	114.	73.	63.	48.	52.
Temperature F.....	53.6	49.	46.4	44.6	41.	43.7	42.	50.	51.8
Bacteria per c.c.....	158.	750.	1620.	2519.	166.	8520.	476.		

CHAPTER VI

RIVER AND STREAM WATER

A VERY large number of cities derive their water-supply from rivers—in Europe after careful filtration, but in America often without such purification.

One of the important things for the consumer of a river-water to bear in mind is that sudden and great changes in its character are to be expected.

For instance, the water of the Hudson River, sampled at a point above direct sewage-inflow (although below several large towns), showed the following variations:

HUDSON RIVER

(Parts per million)

	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Chlorine.	"Required" Oxygen.	Total Residue.	Loss on Ignition.	Suspended Matter (Silt.)	Temperature F°.
Nov. 3....	.030	.087	ooo	trace	3.5	3.76	73.	35.	88.4	....
Dec. 15...	.045	.150	trace	.15	4.5	13.00	107.	42.	68.8	36.
Jan. 12....	.025	.080	ooo	.10	3.5	7.65	43.	39.	ooo	....
Feb. 5.....	.055	.100	ooo	.15	...	8.85	88.	45.	ooo	34.6
March 4...	.085	.150	trace	.10	...	10.00	93.	51.	ooo	33.
April 5....	.042	.235	trace	.30	2.4	5.90	388.	88.	11.	46.4
April 10...	.058	.660	trace	trace	...	15.50	583.	74.	495.	41.
May 8....	.030	.205	trace	.10	2.5	7.30	67.	31.	ooo	68.
June 5....	.045	.120	ooo	trace	3.5	8.70	78.	50.	ooo	71.
Sept. 20...	.280	.320	.0015	.30	5.0	2.65	....	....	....	....
Oct. 30....	.055	.155	trace	....	3.5	14.85	101.	57.	ooo	44.

A river-water which is clear to-day may be muddy and less desirable for use to-morrow.

Fischer gives the following seasonal variations for the water of the Danube (in parts per million):

	Suspended Material	Dissolved Material
Spring	121.9	177.1
Summer	165.4	146.0
Autumn	76.5	178.6
Winter	14.8	199.0

It is to be noted that the bulk of variation lies in the item of suspended material, and that what is in solution is much more constant in amount.*

The Gila river at San Carlos, Arizona, is probably the most muddy in the United States. During the period July 21st to October 24th, 1904, its turbidity varied from 220 to 73,536 parts per million.†

Some idea of the immense quantities of materials carried to the sea by river-flow may be gathered from the fact that the Colorado River discharges per year 338,000,000 tons of suspended silt, in addition to 4,550,000 tons of common salt, 3,740,000 tons of Glauber's salts, 4,000,000 tons of lime, 2,400,000 tons of gypsum and 4,800,000 tons of Epsom salts all held in solution.‡

C. H. Stone, of the U. S. Reclamation Service, reports the following analysis of Mississippi River water § taken May 23, 1905, opposite Nine-Mile point just above Carrollton, in midstream, and about six feet below the surface.

(Expressed in Parts per Million)

Total solids (unfiltered)	1069.
Total solids (filtered)	167.5
Loss on ignition (unfiltered)	74.
Loss on ignition (filtered)	27.5
Si	3.5
Al	0.09
Mn	0.12

* For sundry American data by E. G. Smith see J. Am. Water-works Asso. 1896, p. 88.

† Water Supply and Irrigation Paper No. 151.

‡ U. S. Geol. Sur. Water-Supply Paper 274.

§ Science, Oct. 13, 1905.

Ca	29.5
Mg	6.8
Fe	0.08
K	2.3
Na	10.0
SO_4	28.7
PO_4	0.4
CO_3	0.0
HCO_3	110.4
Cl	16.1
Nitrogen as free ammonia	0.16
Nitrogen as albuminoid ammonia	0.14
Nitrogen as nitrites	0.0
Nitrogen as nitrates	0.23
Oxygen consumed (unfiltered)	14.2
Oxygen consumed (filtered)	3.3
Hardness	109.2
Turbidity	Heavy
Sediment	Large
Odor (cold)	Practically none

RESULTS OF ANALYSIS CALCULATED AS OXIDES

SiO_2	7.4
Al_2O_3	0.17
Fe_2O_3	0.11
Mn_3O_4	0.16
CaO	41.2
MgO	11.3
K_2O	2.8
Na_2O	13.5
SO_3	23.9
CO_2	79.6

The silt from the above water sample was saved and reported upon later by the same chemist.*

Referring to his analysis he says·

* Science, April 20, 1906.

"For the sake of argument let us assume that the above analysis represents the average composition of the silt carried by the Mississippi during the entire year. This is doubtless not quite true, but will serve as a basis for some calculations. One estimate of the total amount of silt carried by the Mississippi during a year places the figures at 443,750,000 tons. Assuming this to be true, the following table gives in tons the amounts of various substances removed in this silt during the year:

$Fe_2O_3+Al_2O_3$	79,431,250
MnO	798,750
CaO	8,120,625
MgO	7,277,500
Na_2O	576,875
K_2O	5,591,250
P_2O_5	1,109,375
SO_3	1,142,500
Total N	665,625
Water and organic matter	31,062,500

"For most of these substances it is impossible to assign any definite commercial value, but for four of them it is possible to compute the actual cost of restoring them to the soil in the form of fertilizer. In the following table such calculation has been made. It has been assumed that the potash would be bought in the form of K_2SO_4, the phosphoric acid as superphosphate and the N as $NaNO_3$. The figures are of course not absolute, but they convey a good idea of the loss which the land has sustained.

"Value of plant food removed in silt by the Mississippi River during one year:

CaO	$40,603,125
K_2O	559,125,000
P_2O_5	110,937,500
N	222,984,375

"These figures are stupendous and worthy of careful consideration, and when we consider that this same process of denudation of the land is being carried on by all the streams of the country, to a greater or less extent, we gather some faint idea of the loss to agricultural interest from this cause."

The surface of the United States is being removed at the rate of thirteen ten-thousandths of an inch a year, or one inch in 760 years, according to the United States Geological Survey. Though this amount seems trivial when spread over the surface of the country, it becomes stupendous when considered as a total, for over 270,000,000 tons of dissolved matter and 513,000,000 tons of suspended matter are transported to tide-water every year by the streams of the United States.*

River-waters contaminated with unusual materials are at times met with. Thus the well-known Rio Vinagre of South America contains 1100 parts of free sulphuric acid and 1200 parts of free hydrochloric acid per million of water. The quantity of free sulphuric acid carried by it to the sea is over fifty tons daily.

In the Youghiogheny River near McKeesport, Pa., the average free acid as H_2SO_4 from Sept. 1, 1906, to Sept. 1, 1907, as given in Water Supply Paper 236, U. S. Geol. Survey, was 22 parts per million. From Oct. 1st to Dec. 1st, 1908 the average was 140 parts.

"The variations in the condition of the water are wide and sudden. On one occasion the acidity increased from 50 to 210 parts per million within three hours."

Some streams of Norway and Sweden furnish water so impregnated with infusion of woody material as to be destructive of fish. Frankforter found "tannates" and "gallates" in the water of the upper Mississippi, due to the enormous number of logs floated down the stream from the great forests of the North.

Judged also the the bacteriological side, flowing water will always show large variation in composition at different times, principally due to introduction of impurities carried down by storms from surface sources. Variation will also be noted at different points of the length, breadth, and depth of the same stream, as common judgment would expect, arising from

* See Science, Dec. 13, 1912.

irregularities in mixing of tributary waters, and from changes in the rate of sedimentation.

Tidal action has also much influence upon the variation in character of certain river-waters. The author has in mind several cities, situated upon large streams, which pump fairly good water during ebb-tide, but whose sewage is carried up-stream by the reversed current of flood-tide, to and beyond the intakes, with exceedingly bad results.

All such points are to be considered when selecting the position for a city's intake.

The pollution of rivers by the progressive introduction of sewage and industrial wastes causes a change that is a more serious matter than those seasonal ones noted above; a change that, although somewhat slow in growth, has the disadvantage of being continually on the increase through the enlarging of the populations which naturally sewer into the rivers.

Many of our rivers are very large, but the volume of city sewage dumped into them is large as well. It is sometimes very great indeed, as for instance the amount that Chicago daily turns into the Illinois River or that Philadelphia pours into the Schuylkill and Delaware.

The Hudson River at the city of New York is not to be rated as a fresh-water stream, but we note that the raw sewage that the Metropolis daily disposes of therein reaches the great volume of five or six hundred million gallons.

Remembering the old rule of law that a riparian owner is entitled to receive from his up-stream neighbor a stream-flow undiminished in quantity or quality, the question presents itself, should the amount of river pollution now existing be permitted to continue.

This question is a very vexed one and it has been answered in sundry ways. Extreme partisans on the one side have raised outcry against making sewers of our rivers and they insist that the waters should be returned to, and maintained in, the state of purity in which the discoverers found them. Those on the other side, equally extreme, insist that rivers and streams,

being the natural drains of the country, should be used as such and should be assigned the duty of carrying to the sea the waste materials of which the valley communities need to dispose.

The author believes that every case of stream pollution should be judged upon its own merits, and he is distinctly opposed to rules or laws of a blanket character, feeling that blanket legislation adjusted to fit one case might do grave injustice if applied to another. As a broad proposition large streams, especially navigable ones, should be considered as draining a country rather than watering it, but nevertheless the up-stream community should not so grossly misuse such a drain as to make it border upon a nuisance and render it difficult or impossible for the down-stream city to use the water for general supply even after applying some reasonable and modern form of water purification. While an up-stream town should not grossly misuse the stream as a drain, they should, nevertheless, not be so unfairly treated as to be required to convert their sewage into drinking-water before dumping it into the river, for the reason that the down-stream community should in justice be asked to bear its appropriate portion of the general expense and employ suitable methods for the purification of its water supply.

Small streams which are in no way navigable should be placed in a different class and more stringent regulations should be enforced to safeguard their purity. Let it be remembered that the "time of flow" between an intake and an up-stream point of pollution is the element of importance, rather than the distance in miles, for the reason that a rapidly moving brook may deliver its load of objectionable material from a distant source more quickly, and consequently in a fresher condition, than can be done by a slowly flowing stream even though the latter draws its pollution from a point nearer at hand. The importance of the esthetic side of the question should be remembered as well, and the general appearance of a stream should be considered when undertaking to determine whether or not its water could be damaged by the introduction of some proposed form of waste discharge.

In short, aside from any consideration of disease development, the introduction of waste material should breed no "nuisance."

Stearns considers that if the volume of the entering sewage be greater than $\frac{1}{10}$ of that of the stream into which it empties, a nuisance will result; if its volume be less than $\frac{1}{130}$ of that of the stream satisfactory results may be counted upon; while if its relative volume be between those figures no prediction can be made.

A convenient form of statement, widely used, is that it will require a volume of stream-flow equal to a certain number of cubic feet per second (i.e., "second-feet") to safely take care of the sewage from 1000 people. In applying this expression attention must be had to the character of the stream itself, as an opportunity for aeration will increase the efficiency of the water to properly care for its dose of sewage, while chances for "pooling" and "stranding" of the suspended solids will have an opposite effect.

After all is said it must be admitted that the values and forms of definition commonly given do not fully cover the situation, nor are we released from any obligation to decide each case upon its own merits; for a nuisance is not to be attributed to sewage discharge alone, nor would the same cause be voted a nuisance by all people. Of two streams with which the writer is familiar the first has the objectionable odor due to waste liquor from a sulphite-pulp mill while the other is stained bright pink by the discharge from dye-works.

Two men, one blind and the other suffering from loss of the sense of smell would give very different interpretations of nuisance as applied to these waters.

In New York law, a nuisance is defined as an act or omission which "annoys, injures, or endangers the comfort, repose, health or safety of any considerable number of persons; or which offends public decency."

If putrescible organic matter be added to a stream in such quantity that the dissolved oxygen is not sufficient to oxidize it, then decomposition in absence of oxygen results with its

attendant offensive odors. Proper aeration is the cure for such a condition but is must be noted that while aeration disposes of the annoyance due to the organic matter it does not destroy germ life.

The killing of fish is one of the objectionable results which follow the undue fouling of a stream by sewage or industrial waste; their gills become clogged with fibrous material and they are deprived of the amount of dissolved oxygen which their well-being demands. Necessarily there is considerable difference in the quantity of oxygen which different kinds of fish require; thus coarse varieties are able to do with a smaller percentage of saturation than is needed for trout and other fish of delicate organism.

Speaking generally, fish should be furnished with dissolved oxygen to an amount equal to from 30 to 50 per cent of saturation.

Weigelt records the following observations of the effects upon fish of waters contaminated with products of industrial waste: *

Contained in One Million Parts of Water.	Kind of Fish Used.	Observations.
70 slaked lime, $Ca(OH)_2$	Trout	Dead in 26 minutes.
1000 soda, $Na_2CO_3 \cdot 10H_2O$	"	After 3 minutes, restless.
0.5 chloride of lime, $CaCl_2O$	"	Dead in 3 hours.
100 hydrochloric acid, HCl	"	On its side in 4 minutes.
100 sulphuric acid, H_2SO_4	"	On its side at once.
50 ammonia, NH_3	"	Dead in 47 minutes.
100 sodic arsenate $Na_2AsO_4 \cdot 12H_2O$	"	Strong effect.
50 mercuric chloride, $HgCl_2$	"	Dead in 54 minutes.
1000 calcium chloride, $CaCl_2$	"	An effect in 2 hours.
100 green vitriol, $FeSO_4 \cdot 7H_2O$	"	Dead in 5 hours.
50 green vitriol, $FeSO_4 \cdot 7H_2O$	"	No effect in 16 hours.
1000 iron chloride, $FeCl_3$	"	On its side in 3 minutes.
1000 manganese chloride, $MnCl_2$	"	Speedy restlessness.
5 carbolic acid, C_6H_5OH	"	Restless in 15 minutes.
1000 soap (unfiltered)	Salmon	Dead in 1½ hours.
1000 soap (filtered)	"	No effect.

* " Das Wasser," Fischer, p. 52.

H. W. Clark * in his paper on "Fish Life and Water Pollution" finds the following chemicals fatal to fish if present in the amounts here stated as parts per million: †

$(NH_4)_2CO_3$	55 to 70
NH_4OH	13
Na_2CO_3	250
$NaOH$	70
NH_4Cl	180 had no effect

Iron in solution was found "very fatal."

In water very slightly acid with nitric acid "the fish not only neutralized the acid but made the water alkaline."

He found that a one-pound fish used up all the dissolved oxygen in one gallon of water at 60° F. in one hour.

In the same paper the above author gave the following data dealing with the effect of sundry sewage dilutions upon fish life:

In straight sewage, kept well aerated (i.e., containing 50 to 100 per cent dissolved oxygen), all fish died within a few minutes.

When water and sewage, *well aerated*, were mixed in equal portions some fish lived indefinitely, but with a larger proportion of sewage to the water they died in a few minutes. The above 1 : 1 mixture was fatal to all except robust individuals. The sewage used was freed from suspended matters.

Effluents from successful "contact-beds" and "trickling-filters," if kept well aerated, sustained fish life indefinitely.

Mixtures of straight (but strained) sewage and tap water, *not artificially aerated*, could not sustain fish life if the sewage were over 10 per cent of the mixture.

Substituting a "trickling-filter" effluent for the sewage the water in the mixture did not have to exceed 25 per cent

* Eighth International Cong. App. Chem., Sec. VIII*a*.

† For the action of $CuSO_4$ upon fish see page 321.

to sustain fish life, but with " contact-bed " effluents the water had to be at least 50 per cent of the mixture.

Rideal * calls attention to the manifest truth that while the death of fish points towards an objectionable water, the fact that they live is by no means a guarantee of purity. He adds: " Fish are more affected by muddy water and by chemicals from factories than by excreta."

The dissolved oxygen required by the major fish life is almost entirely the result of direct solution from the air, but it should be remembered that the atmospheric gases are not equally soluble in water; the ratio of oxygen to nitrogen in the " boiled-out air " is different from the atmospheric relation because of the greater solubility of the oxygen.

With reference to the question of dissolved oxygen a great deal of painstaking work was done by the Metropolitan Sewage Commission and the data secured form no small part of the record in the case of New York vs. New Jersey before the U. S. Supreme Court in the matter of the pollution of the waters of New York Bay.

It was of course necessary in that case to recognize the fact that oxygen dissolves in sea-water less readily than it does in fresh water, the values (at 17° C. and 760 m.m. pressure) being. †

Sea-water	5.6 c.c. per litre
Fresh water	6.9 "

As supplementary to what has already been said regarding the self-purification of streams, a word may be added to the effect that when the end desired is the prevention of the sewage-inflow to a river becoming a nuisance, rather than the preservation of the potable character of the water, then unquestionably falls and rapids become of material value, for they are the means of increasing the supply of dissolved oxygen held by the water, and upon the quantity of such oxygen present

* " Sewage," page 44.

† Report Metro. Sewer Com., 1910, p. 410.

the capacity of the stream to satisfactorily dispose of a nuisance following sewage-inflow largely depends.

RAINFALL, EVAPORATION, AND FLOW OF STREAMS

Rainfall is greatest within the tropics and near the sea, and it lessens near the poles. In the same general district it also tends to increase with elevation above sea-level, but local disturbing factors enter to offset this tendency and introduce irregularities. The average annual precipitation for the north temperate zone is usually estimated at 35 inches.

The great volume of water represented by a heavy rainfall is not generally appreciated, thus one inch of rain falling upon an area of one square mile corresponds to 2,323,200 cubic feet of water, or nearly 17,500,000 U. S. gallons.

Exceptionally heavy rainfalls are not, for our purpose, expecially worthy of record; but it may be interesting to note, very briefly that the greatest concentrated rainfall on record is reported by the Catholic meteorological station at Manila, P. I., as having occurred in Western Luzon. During three days the total rainfall recorded at Baguio was 88 inches, 32 inches of which is reported to have fallen during the first twenty-four hours.*

A further list of very heavy rainfalls may be found in Rafter and Baker, "Sewage Disposal," page 134. See also Senate Doc. 91, 50th Congress.

"There is a theory which numbers of people accept as true, that great battles have been generally, if not invariably, closely followed by storms.

"This belief is deeply rooted in the popular mind, somewhat like the various notions held by many people in relation to the effects of the moon's phases upon the weather And it appears to be a traditional idea, for the belief that battles cause rain was prevalent before the invention of gunpowder." †

"While the question of rain-making by the use of explosives

* Engineering News, Nov. 30, 1911.
† Am. Met. Jour., March, 1892.

was under consideration at Washington the scientists of the Department of Agriculture made a thorough investigation of the subject, with all the records of the government at their command, and the conclusion reached was that there is no foundation for the opinion that days of battle were followed by rain any more than days when it was all quiet along the lines." *

There is no record showing any relation between rainfall and the tremendous battles which have occurred during the present great war.

Regarding the relation of great fires to rainfall, Prof. I. A. Lapham, of the U. S. Signal Service, writes of the Chicago fire as follows:

"During all this time—twenty-four hours of conflagration upon the largest scale—no rain was seen to fall, nor did any fall until four o'clock the next morning; and this was not a very considerable downpour, but only a gentle rain that extended over a large district of country, differing in no respect from the usual rains. It was not until four days afterward that anything like a heavy rain occurred. It is, therefore, quite certain that this case cannot be referred to as an example of the production of rain by a great fire."

The following chart and statistics † show the normal rainfall of the United States, and also the same data for separate States.

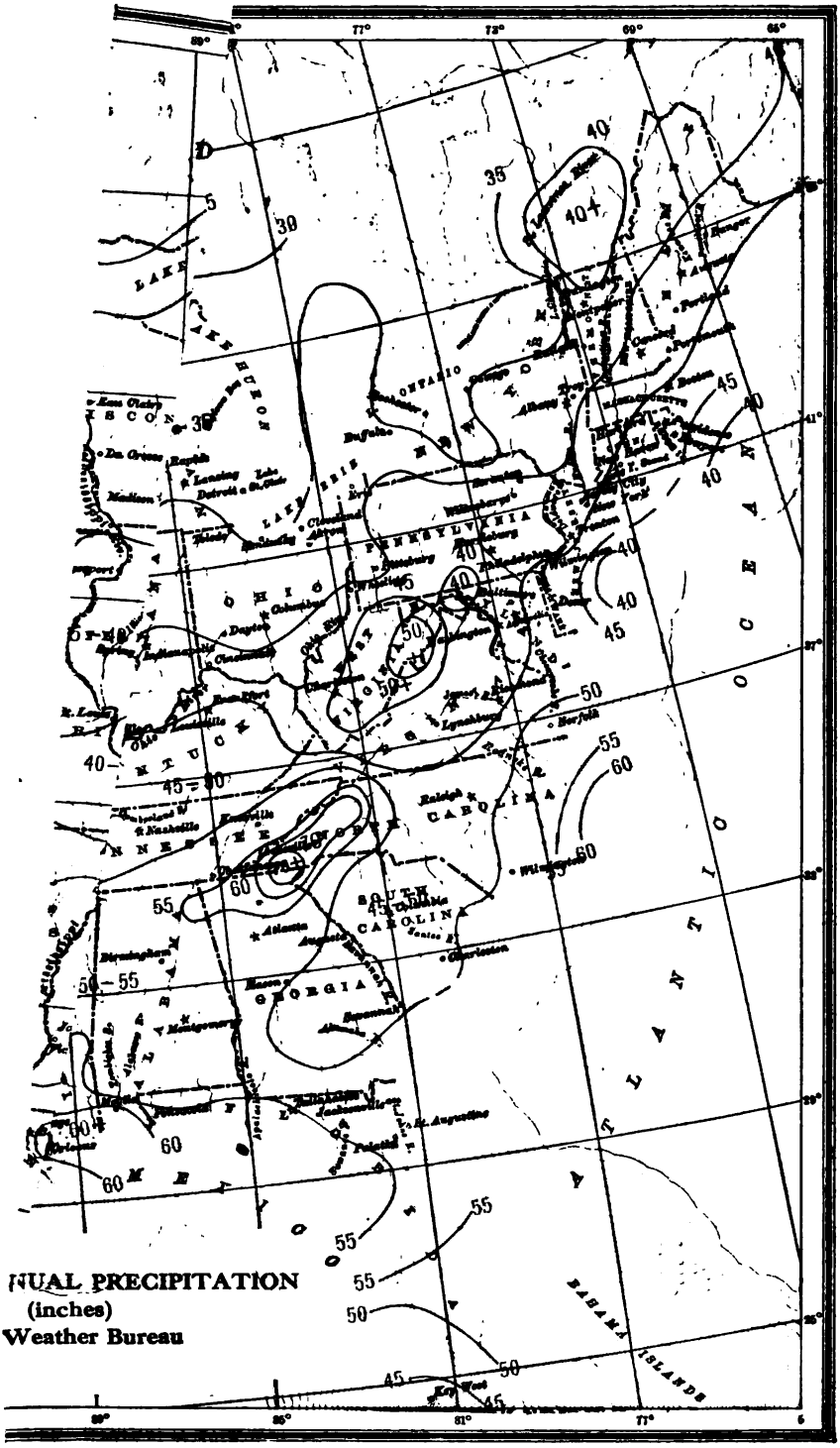
RAINFALL AND SNOW OF THE UNITED STATES

Annual and seasonal averages, seasonal variation and cubic miles for each State.

State.	Area in Square Miles.	Spring.	Summer.	Autumn.	Winter.	Annual.	Seasonal Variation	Cubic Miles.
		Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	
Alabama	52,250	14.9	13.8	10.0	14.9	53.6	1.5	44.2
Arizona	113,020	1.3	4.3	2.2	3.1	10.9	3.3	19.4
Arkansas	53,850	14.3	12.5	11.0	12.8	50.6	3.9	42.5
California	158,360	6.2	0.3	3.5	11.9	21.9	40.0	54.9
Colorado	103,925	4.2	5.5	2.8	2.3	14.8	2.4	24.2

* Sage, Iowa Weather and Crop Service.

† Report of the Chief of the U. S. Weather Bureau.


NUAL PRECIPITATION
(inches)
Weather Bureau

RAINFALL AND SNOW OF THE UNITED STATES—*Continued.*

State.	Area in Square Miles.	Spring.	Summer.	Autumn.	Winter.	Annual.	Seasonal Variation	Cubic Miles.
		Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	
Connecticut	4,990	11.1	12.5	11.7	11.5	46.8	1.1	3.6
Delaware	2,050	10.2	11.0	10.0	9.6	40.8	1.1	1.3
District of Columbia	70	11.0	12.4	9.4	9.0	41.8	1.4	0.04
Florida	58,680	10.2	21.4	14.2	9.1	54.9	2.4	51.0
Georgia	59,475	12.4	15.6	10.7	12.7	51.4	1.5	48.2
Idaho	84,800	4.4	2.1	3.6	7.0	17.1	3.3	22.7
Illinois	56,650	10.2	11.2	9.0	7.7	38.1	1.5	34.0
Indiana	36,350	11.0	11.7	9.7	10.3	42.7	1.2	24.2
Indian Territory	31,400	10.6	11.0	8.9	5.7	36.2	1.9	17.7
Iowa	56,025	8.3	12.4	8.1	4.1	32.9	3.0	28.8
Kansas	82,080	8.9	11.9	6.7	3.5	31.0	3.4	40.0
Kentucky	40,400	12.4	12.5	9.7	11.8	46.4	1.3	29.3
Louisiana	48,720	13.7	15.0	10.8	14.4	53.9	1.4	41.6
Maine	33,040	11.1	10.5	12.3	11.1	45.0	1.2	23.2
Maryland	12,210	11.4	12.4	10.7	9.5	44.0	1.3	8.3
Massachusetts	8,315	11.6	11.4	11.9	11.7	46.6	1.0	5.9
Michigan	58,915	7.9	9.7	9.2	7.0	33.8	1.4	31.3
Minnesota	83,365	6.5	10.8	5.8	3.1	26.2	3.5	34.4
Mississippi	46,810	14.9	12.6	10.1	15.4	53.0	1.5	38.8
Missouri	69,415	10.0	12.4	9.1	6.5	38.0	1.9	41.2
Montana	146,080	4.2	4.9	2.6	2.3	14.0	2.1	32.1
Nebraska	77,510	8.9	10.9	4.9	2.2	26.9	5.0	32.9
Nevada	110,700	2.3	0.8	1.3	3.2	7.6	4.0	14.4
New Hampshire	9,305	9.8	12.2	11.4	10.7	44.1	1.2	6.3
New Jersey	7,815	11.7	13.3	11.2	11.1	47.3	1.2	5.6
New Mexico	122,580	1.4	5.8	3.5	2.0	12.7	4.1	24.5
New York	49,170	8.5	10.4	9.7	7.9	36.5	1.3	28.3
North Carolina	52,250	12.9	16.6	12.0	12.2	53.7	1.4	44.2
North Dakota	70,795	4.6	8.0	2.8	1.7	17.1	4.7	19.1
Ohio	41,060	10.0	11.9	9.0	9.1	40.0	1.3	25.7
Oregon	96,030	9.8	2.7	10.5	21.0	44.0	7.8	66.7
Pennsylvania	45,215	10.3	12.7	10.0	9.5	42.5	1.3	30.2
Rhode Island	1,250	11.9	10.7	11.7	12.4	46.7	1.2	0.8
South Carolina	30,570	9.8	16.2	9.7	9.7	45.4	1.7	21.6
South Dakota	77,650	7.2	9.7	3.5	2.5	22.9	3.9	28.1
Tennessee	42,050	13.5	12.5	10.2	14.5	50.7	1.4	33.4
Texas	265,780	8.1	8.6	7.6	6.0	30.3	1.4	127.0
Utah	84,970	3.4	1.5	2.2	3.5	10.6	2.3	14.3
Vermont	9,565	9.2	12.2	11.4	9.3	42.1	1.3	6.1
Virginia	42,450	10.9	12.5	9.5	9.7	42.6	1.3	28.5
Washington	69,180	8.6	3.9	10.5	16.8	39.8	4.3	43.4
West Virginia	24,780	10.9	12.9	9.0	10.0	42.8	1.4	16.6
Wisconsin	56,040	7.8	11.6	7.8	5.2	32.5	2.2	28.7
Wyoming	97,890	4.3	3.5	2.2	1.6	11.6	2.7	17.9
Total	2,985,850	....	....	....	....	....	..	1407.14
Average	.....	9.2	10.3	8.3	8.6	36.3	3.0	.....

"A very remarkable feature in the rainfall of the United States, appearing on most of the monthly maps, and distinctly on the annual map, is the way in which certain peaks and ranges of mountains are outlined by the mean rainfall.

"Another series of facts of very great interest can be read from the maps in the consideration of the relations of rainfall to the leeward and windward sides of the ranges. This is by far the best marked on the Pacific coast, where the prevailing winds are distinctly from the west and reach the coast laden with moisture from the warm ocean. To the westward, for instance, of the Sierra Nevadas on the annual map there is a rainfall of from 20 to 40 inches. Immediately to the eastward of this series of mountains the annual rainfall is only from 2 to 6 inches. Much the same is true of the Cascade Range, and even the Coast Range has a very marked influence on the rainfall. The annual line, for instance, of 40 inches of rainfall passes down the coast from Vancouver Island almost parallel to and westward of the Coast Range, although for most of this distance these mountains are quite low.

"Another curious fact which may be mentioned in connection with the general rainfall of the United States is that, generally, the great swampy areas occur in regions of highest rainfall. This is true, for instance, of the everglades of Florida, where the rainfall is from 50 to 70 inches per year. It is also true of the great swampy district lying on the coast of North Carolina, where the rainfall is 60 inches per year, and upward; also of the swampy district about the mouth of the Mississippi River; but is not so true of the celebrated swampy district lying to the west of the Mississippi along the Gulf coast.

"It is interesting to notice the effects of the Great Lakes on the rainfall visible on most of the maps. In general, it will be found that the rainfall is greater on the east shore of Lake Michigan than on the west shore. It is to be noted that the prevailing winds here reach the lake from the west. Either they gather up considerable moisture from the lake which is deposited on the east shore, or, what is more probable, the

temperature of the lake is such as to chill the air and cause it to deposit more of its moisture on the east shore than on the west. Much the same is true of the east shores of Lake Erie and Lake Ontario, areas which are small in both cases, because the lakes themselves lie east and west. There is, however, a distinct increase of rainfall along the southeastern coast of Lake Erie and to the east of Lake Ontario. These features can be traced on the monthly maps, but more perfectly on the seasonal ones. The effect seems to be somewhat more marked in the cold seasons than in the warm, and it is a noteworthy fact that the areas of deep snows in Michigan and New York are found to be on the same line. The area of deep snows for Southern Michigan is from the middle of the west coast, in the vicinity of Manistee, nearly straight across the peninsula; the area of deep snowfall in New York is to the eastward of Lake Ontario, and, to some degree, to the southward, in the immediate vicinity of the lake. It should also be noted that the area for deepest snow in the United States not mountainous is along the south shore of Lake Superior, from Marquette eastward. This would quite agree with the suggested influence of the lakes, in that the air passing over Lake Superior comes largely from the northwest, and by the time it reaches the coast in question has already received a surcharge of vapor chilled by the surface of this lake.

"Another interesting point is the average rainfall for the entire United States. The average of all stations, by States, gives for spring 9.2 inches, for summer 10.3 inches, for autumn 8.3 inches, and for winter 8.6 inches, and a total for the year of about 36 inches. It appears that the rainfall over the United States generally is quite evenly distributed through the year, varying in total amount for the seasons from 10.3 for summer to 8.3 for autumn. The spring and summer rainfalls are the highest; other things being equal, the rainfalls of spring and, next to that, of summer are the most useful for agricultural operations.

"With the depth given it is not difficult to get the average total rainfall for the entire United States (excluding Alaska,

where we have not sufficient information). For this purpose we may take the average for each State and multiply it by the area of the State, including water-surfaces. Adding these together we get 1407 cubic miles as the average annual total of water which descends as rain or snow in the United States. The figures for the areas are taken from the census of 1890. The annual depth of rainfall which this gives is 29 inches, or less than that given by the other method. This is to be expected, as the other method gave equal weight to each political division, and these divisions are generally smaller in the regions of greater rainfall.

"To get some conception of this enormous mass of water we may compare it with the contents of the Great Lakes, and an approximate comparison is near enough. Lake Ontario is about 200 miles long and 70 broad, and its average depth is about 40 fathoms. It therefore contains about 636 cubic miles of water. The annual rainfall would fill it two times and leave something over for a third time. Lake Michigan is about 310 by 70 miles and has an average depth of about 50 fathoms, and consequently contains about 1233 cubic miles of water. The average annual rainfall would fill Lake Michigan and leave 174 cubic miles over. Four years of rainfall would probably be enough to fill all the Great Lakes." (U. S. Weather Report.)

The average rainfall of the whole earth has been computed at 36 inches per annum.* It is interesting to note that the same figure answers for the average for the United States (36.3) and also for the average for the State of New York (36.5).

The wettest place in the world is Cherrapungi, in the Khasi Hills, Assam, 4455 feet above sea level, where the annual rainfall varied between 500 inches and 600 inches, and in the year 1891 it was 920 inches. †

Middleton ‡ arrives at the available rainfall by taking the average, deducting the local evaporation and then deduct-

* Water and Water Engineering, Nov. 1913.
† Ibid., paper 313.
‡ "Water Supply," p. 52.

ing further one-fifth of the average rainfall to allow for three successive dry years.

Binnie considers that a good record covering thirty-five years will give an average rainfall that will be correct within 2 per cent, while Henry holds that forty years are required and that even then the result cannot be trusted nearer than 5 per cent.*

"Years of large or maximum rainfall recur at intervals of approximately ten years, while the years of low or minimum rainfall recur at much longer intervals." †

SEVERE DROUGHTS IN THE MIDDLE STATES ‡

"Mr. C. Warren furnishes the following from records giving the length of the most noted dry spells in the Middle States:

In the summer of 1634, 24 days.
In the summer of 1637, 74 days.
In the summer of 1642, 41 days.
In the summer of 1662, 80 days.
In the summer of 1664, 45 days.
In the summer of 1688, 81 days.
In the summer of 1694, 92 days.
In the summer of 1705, 30 days.
In the summer of 1715, 46 days.
In the summer of 1728, 61 days.
In the summer of 1730, 92 days.
In the summer of 1741, 72 days.
In the summer of 1745, 72 days.
In the summer of 1754, 108 days.
In the summer of 1755, 24 days.
In the summer of 1763, 133 days.
In the summer of 1773, 80 days.
In the summer of 1791, 82 days.
In the summer of 1812, 28 days.
In the summer of 1856, 26 days.
In the summer of 1871, 42 days.
In the summer of 1875, 26 days.
In the summer of 1876, 26 days.

"The longest drought above mentioned, which occurred in 1763, began on the first day of May, and many inhabitants of this country were compelled to send to Europe for grain and hay.

"It should be noted that the longest period of drought in the above records occurred over a century ago, at which time but little progress had been made in clearing the vast forests, draining the ponds, tilling the fields, and making that section

* J. N. E. Water Works Asso., xviii. 33.
† Ibid., xviii. 35.
‡ Iowa Weather Service.

of the country habitable for civilized man. A careful study of records covering all the years since the early settlement of this country does not disclose any appreciable decrease or increase in the seasonal precipitation, or in the temperature and humidity of the air."

Some Historic Droughts.—"There have been droughts in all ages and countries. In the year 310 A.D. hardly a drop of water fell in England, and 40,000 people died of famine.

"The seven years of drought and famine in Egypt, recorded in Genesis, began in the year 1708 B.C.

"In 954 a drought began in Europe, lasting four years. The summers were intensely hot and the famine prevailed everywhere; 3,000,000 died of hunger.

"In 1771 an unprecedented drought prevailed throughout India. Scarcely any rain fell for a year, and hundreds of thousands died of famine, whole districts being depopulated.

"In 1837 drought and intensely hot weather prevailed in Northwest India. Over 800,000 persons perished from famine. Similar destruction was wrought by the same causes in 1865 and 1866, over 2,000,000 persons perishing of hunger in the two years."

Evaporation measurements, both for land and water surfaces, have been conducted at certain points of the United States, and the results have been recorded by such competent observers as Desmond FitzGerald, W. J. McAlpine,* Professor Fuertes, T. Russell, and others. From the reports of these gentlemen and from other official sources the following data have been drawn:

Prof. T. Russell, Jr., obtained the following results from

* Wm. J. McAlpine, in a report to the Water Committee of Brooklyn in 1852, finds "that from 30 to 40 per cent of the falling rain and snow is carried off by evaporation." The experiments were made by himself. In the same report the quotations are found as to the mean evaporation in inches at the following places:

Great Britain	32 inches per annum
Paris	38 " "

experiments designed to show relative rate of evaporation as affected by rate of wind motion. Compared with the evaporation from a water-surface when covered by still air, the evaporation from the same surface when the wind showed different velocities was as follows: Wind 5 miles per hour, evaporation 2.2 times. Wind 10 miles per hour, evaporation 3.8 times. Wind 15 miles per hour, evaporation 4.9 times. Wind 20 miles per hour, evaporation 5.7 times. Wind 25 miles per hour, evaporation 6.1 times. Wind 30 miles per hour, evaporation 6.3 times. These experiments were made when the temperature of the air was 84° F. and the humidity was 50 per cent.*

At Rothamsted, England, with an average annual rainfall of 31.04 inches, it was found that evaporation from bare soil amounted to 17.09 inches, and that 13.95 inches percolated to a depth exceeding five feet, and appeared as drainage. Of these 13.95 inches of drainage 9.44 inches collected during five months, beginning in October, and the remaining seven months furnished only 4.51 inches, showing that the ground-water depended upon winter drainage for its principal reinforcement.†

"Evaporation from saturated woodland soil is from 61 to 63 per cent less than from saturated soil in the open, the rainfall in woodland commonly exceedingly the evaporation, even in summer.

"Woldrich found that less water percolated in soil upon which grass was growing than upon a bare soil. Very light rains were wholly lost by evaporation from the grass. He also noted that when the snow melted in the spring the water from it passed from it into the bare land quicker and in larger quantity than it did into the soil that was grass-covered.

"According to Wollny, a calcareous loam which permitted 38 per cent of the rainfall to soak through when it was bare of vegetation percolated no more than 20 per cent of the rainfall when grass or clover was growing upon it." (Storer.)

* Iowa Weather and Crop Service, Feb., 1904.

† J. Chem. Soc., li. 504.

TABLE SHOWING RELATION OF EVAPORATION TO RAINFALL (MASSACHUSETTS)

Month.	Average Year.			Year of Low Rainfall (1883).		
	Rainfall, Inches.	Evaporation, Inches.	Excess or Deficiency of Rainfall, Inches.	Rainfall, Inches.	Evaporation, Inches.	Excess or Deficiency of Rainfall, Inches.
January	4.18	0.98	+3.20	2.81	0.98	+1.83
February	4.06	1.01	+3.05	3.86	1.01	+2.85
March	4.58	1.45	+3.13	1.78	1.45	+0.33
April	3.32	2.39	+0.93	1.85	2.39	−0.54
May	3.20	3.82	−0.62	4.18	3.82	+0.36
June	2.99	5.34	−2.35	2.40	5.34	−2.94
July	3.78	6.21	−2.43	2.68	6.21	−3.53
August	4.23	5.97	−1.74	0.74	5.97	−5.23
September	3.23	4.86	−1.63	1.52	4.86	−3.34
October	4.41	3.47	+0.94	5.60	3.47	+2.13
November	4.11	2.24	+1.87	1.81	2.24	−0.43
December	3.71	1.38	+2.33	3.55	1.38	+2.17
	45.80	39.12	+6.68	32.78	39.12	−6.34

NOTE. + indicates excess of rainfall; − indicates deficiency.

In the year of low rainfall the evaporation was 6.34 inches greater than the rainfall. During the warmer months, from April to September inclusive, the excess of evaporation was 15.22 inches, and during the other six months the rainfall was 8.88 inches in excess of the evaporation. These figures indicate that a pond will not lower by evaporation in a dry summer more than about fifteen inches, even if it received no water from its watershed.

Just determination of the rate of evaporation is a decidedly difficult problem to solve, for there exist so many disturbing factors which must be taken into consideration—such as direction and force of wind, character of soil, influence of crops, and like matters—all of which tend to make the final result one of only local application.

Figures that probably represent the maximum evaporation rate for the United States are from a year's record at Yuma, Ariz. The difference between them and those showing the rainfall are marked.* The record was kept by W. D. Smith, observer for the U. S. Geol. Survey.

* Engineering News, 51:248.

1903.	Evaporation, Inches.	Rainfall, Inches.
January	3.32	.00
February	3.48	.23
March	5.28	.00
April	7.21	.00
May	9.84	.00
June	10.25	.00
July	10.75	.04
August	10.70	.00
September	9.05	.67
October	5.79	.04
November	3.80	.00
December	3.39	.00
	82.86	.98
	.98	
Net evaporation	81.88	

Plant requirements, although not strictly to be classed with evaporation, are commonly thought of in that connection, as they represent water losses similar in character.

"After extensive investigation it has been established that the rain which falls upon a crop during its growth is insufficient for its maintenance, and that such a crop would die were it cut off from drawing upon the reserve water stored up in the ground.

"About one quarter of a summer rainfall may cling to the leaves of trees and evaporate directly therefrom, while at the same time the trees act as pumping-engines to dry the ground, owing to evaporation from their enormous leaf-surface. Thus clay lands often become very wet after the cutting off of the trees." (Storer.)

The following is Risler's table of daily consumption of water for different crops, quoted in an article on irrigation by W. Tweeddale: *

	Inches.		Inches.
Lucern grass	from 0.134 to 0.267	Indian corn	from 0.110 to 1.570
Meadow-grass	from 0.122 to 0.287	Clover	from 0.140 to .....
Oats	from 0.140 to 0.193		

* Kansas State Board of Agriculture Report, December 31, 1889.

	Inches.
Vineyard	from 0.035 to 0.031
Wheat	from 0.106 to 0.110
Rye	from 0.091 to .....
Potatoes	from 0.038 to 0.055
Oak-trees	from 0.038 to 0.030
Fir-trees	from 0.020 to 0.043

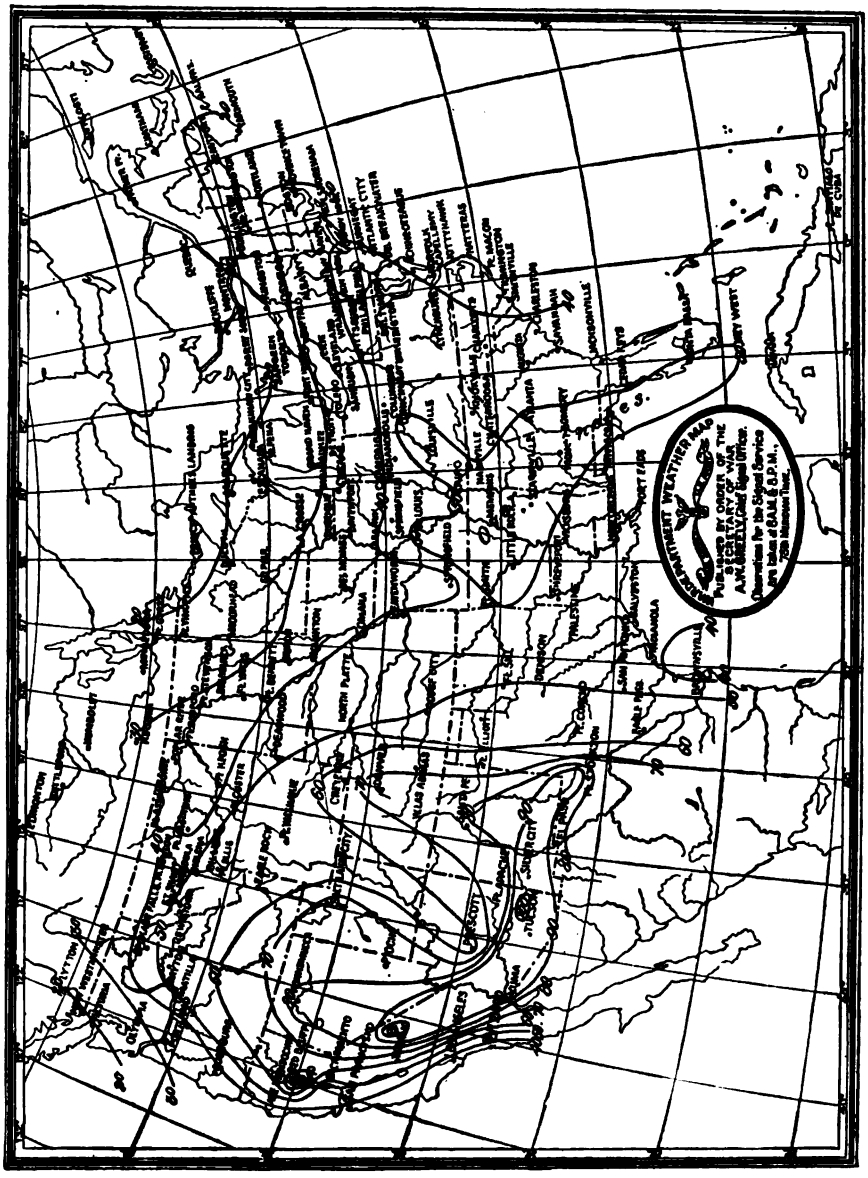
Snyder gives similar data in a different form.* He places the average amount of water, in tons, required for the production of an average acre of various crops as follows:

Clover	400 tons of water
Potatoes	400 "
Wheat	350 "
Cats	375 "
Peas	375 "
Corn	300 "
Grapes	375 "
Sunflowers	6000 "

An average rainfall of two inches per month during the three months of crop-growth would be equivalent to 369 tons of water per acre.

M. Tweeddale concludes that "from seed-time to harvest cereals will take up fifteen inches of water, and grasses thirty-seven inches. These conclusions agree with practice in irrigation, and show plainly that the demands of plant-growth cannot be ignored in tracing the disappearance of rain. The figures also exlpain the low summer flow of streams flowing from a highly cultivated watershed. They do not necessarily explain the effect of forests in regulating flow, since many watersheds, although cleared of trees, are not put under cultivation, but still some change in flow. The action of forests is probably largely to retard surface-flow by means of irregular surfaces, caused by roots, fallen timber, absorbent mosses, and leaf accumulation, thus holding the water until it can

* Chemistry of Soils and Fertilizers, p. 25.



LINES OF EQUAL ANNUAL DEPTH OF EVAPORATION IN INCHES, FROM A FREE WATER-SURFACE. BASED ON OBSERVATIONS FROM JULY, 1887, TO JUNE, 1888, INCLUSIVE.

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL-SERVICE STATIONS, IN THERMOMETER SHELTERS

Computed from the means of the tri-daily determinations of dew-point and wet-bulb observations

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
New England.													
Eastport	0.9	1.4	1.5	2.4	2.5	2.7	2.2	2.9	2.5	2.6	2.2	1.4	25.2
Portland	1.0	1.2	1.8	2.6	1.8	3.3	3.8	3.9	3.4	3.0	2.5	1.4	29.7
Manchester	0.9	1.6	2.2	3.3	3.8	5.0	4.1	3.3	2.5	2.8	2.4	1.4	33.3
Northfield	0.8	1.0	1.5	2.3	2.5	3.4	3.5	2.7	2.3	1.8	1.1	1.0	23.9
Boston	1.2	1.6	2.2	3.4	3.1	4.7	4.4	4.0	3.5	2.7	2.2	1.4	34.4
Nantucket	1.1	1.1	1.2	1.5	1.8	2.1	3.3	3.8	3.4	2.7	1.8	1.8	25.6
Wood's Holl	0.5	0.8	1.8	2.4	1.8	2.7	2.7	2.4	2.7	1.2	0.8	0.5	20.3
Block Island	1.1	1.1	1.2	2.0	1.8	2.6	2.5	3.1	2.8	2.6	1.8	1.4	24.0
New Haven	1.1	1.6	1.8	2.7	2.7	4.1	3.7	3.8	3.1	3.2	2.4	1.6	31.8
New London	1.5	1.3	1.5	2.6	2.8	4.0	3.4	3.9	3.2	3.1	2.4	2.1	31.8
Mid. Atlantic States.													
Albany	0.9	1.2	1.6	3.3	3.9	4.5	5.0	4.7	3.2	3.0	2.1	1.4	34.8
New York City	1.8	1.4	2.0	3.4	3.3	4.6	5.0	5.2	4.3	4.1	3.3	2.2	40.6
Philadelphia	1.6	2.1	2.5	4.4	4.0	5.7	5.7	5.2	4.3	4.0	3.3	2.2	45.0
Atlantic City	1.2	1.6	1.5	2.4	1.8	3.6	2.9	3.3	2.4	1.8	1.2	1.5	25.2
Baltimore	2.0	2.2	2.8	5.1	4.7	5.6	6.0	5.0	4.4	4.3	3.6	2.4	48.1
Washington City	1.8	1.7	2.5	4.2	3.8	6.0	5.4	4.9	4.1	4.2	4.5	2.5	45.6
Lynchburg	2.6	2.7	3.4	3.2	4.5	5.6	4.7	4.3	3.3	3.4	3.2	2.6	45.5
Norfolk	1.8	1.6	2.3	3.5	3.2	4.2	4.6	3.7	3.7	2.9	2.3	1.8	35.6
So. Atlantic States.													
Charlotte	2.6	2.6	4.3	0.4	4.5	5.8	4.0	4.0	4.6	4.0	3.6	2.6	49.0
Hatteras	1.8	1.6	1.6	2.5	2.2	3.0	3.3	4.1	3.8	3.2	2.0	1.6	31.3
Raleigh	2.0	1.8	2.6	3.8	4.1	5.4	4.2	3.2	3.0	2.7	2.4	1.8	37.0
Wilmington	2.4	2.2	2.7	3.3	3.3	4.3	4.3	3.1	3.9	3.4	2.8	2.7	38.4
Charleston	2.5	2.5	3.5	3.7	3.9	4.4	4.5	4.8	4.2	4.0	3.2	2.5	43.7
Columbia	2.2	2.3	2.6	4.8	4.3	5.4	4.2	3.8	4.2	3.4	3.6	2.4	43.2
Augusta	3.0	2.6	3.4	5.3	4.8	5.0	4.8	4.5	5.1	4.1	3.6	3.1	49.3
Savannah	3.3	2.8	4.1	4.7	4.3	4.6	4.2	4.7	3.4	3.6	3.5	2.8	46.0
Jacksonville	2.9	2.6	3.8	4.3	4.6	5.3	5.0	4.7	3.8	3.6	3.0	2.1	45.7
Florida Peninsula.													
Titusville	3.5	2.6	3.3	3.8	3.8	4.3	3.8	4.3	4.0	4.1	3.6	3.1	44.2
Cedar Keys	3.3	2.8	4.0	4.6	4.5	5.1	5.0	5.5	4.5	4.1	3.5	2.6	49.5
Key West	3.8	3.7	3.8	4.5	4.4	4.8	5.1	5.1	4.7	4.3	3.8	3.6	51.6
Eastern Gulf States.													
Atlanta	2.7	2.6	4.0	6.2	4.7	5.0	4.5	4.7	5.8	4.6	4.2	2.5	51.5
Pensacola	2.9	2.8	4.1	4.0	4.3	4.6	5.0	5.4	5.2	4.5	3.6	2.4	48.8
Mobile	2.6	2.5	2.8	3.5	3.7	4.0	4.1	4.6	4.6	4.1	3.4	2.2	42.1
Montgomery	3.5	3.3	5.1	6.5	5.9	5.8	4.3	4.5	5.7	4.6	4.3	3.1	56.6
Vicksburg	2.1	2.5	3.6	5.1	5.7	4.8	4.0	5.0	4.7	3.4	4.0	2.2	47.1
New Orleans	2.8	2.8	4.1	3.8	4.2	4.1	4.1	4.3	4.4	4.6	3.7	2.5	45.4

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL-SERVICE STATIONS.—*Continued*

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
Western Gulf States.													
Shreveport	1.6	2.1	3.0	4.8	4.9	4.2	4.9	5.2	5.0	4.1	3.4	2.4	45.6
Fort Smith	2.2	2.7	3.5	5.3	4.4	4.6	5.6	4.6	4.7	5.9	3.9	2.2	49.6
Little Rock	2.1	2.8	3.5	5.5	4.8	4.1	5.4	5.9	5.8	5.2	4.3	2.3	51.7
Corpus Christi	1.4	1.6	3.3	3.0	3.2	3.9	4.4	4.3	4.3	4.1	3.0	2.3	38.8
Galveston	1.6	2.8	3.2	2.9	4.3	4.2	5.3	5.2	5.2	4.7	4.2	2.4	46.0
Palestine	2.1	3.0	3.3	4.2	4.3	4.5	5.8	4.6	4.8	4.4	4.0	2.1	47.1
San Antonio	2.4	3.3	4.1	3.8	4.0	4.5	6.6	5.8	5.2	5.4	4.2	3.1	52.4
Rio Grande Valley.													
Rio Grande City	2.7	3.5	3.5	3.6	4.5	4.6	6.9	7.0	5.2	4.9	3.6	3.1	53.1
Brownsville	1.8	2.6	2.9	3.0	3.5	3.9	4.0	4.1	3.3	3.0	2.6	2.3	37.0
Ohio Val. & Tenn.													
Chattanooga	2.0	3.3	3.3	5.3	3.7	4.3	4.3	5.0	5.4	4.0	3.9	1.9	46.4
Knoxville	2.4	2.6	3.4	5.0	3.5	4.2	4.9	5.0	4.9	4.1	3.8	2.1	45.9
Memphis	2.1	2.3	3.1	5.9	5.3	4.8	4.9	5.4	5.5	4.2	4.1	2.4	50.0
Nashville	1.9	2.1	3.2	5.9	5.0	5.1	5.5	6.3	5.9	4.0	3.3	1.9	50.1
Louisville	1.7	2.1	2.8	5.6	5.4	5.8	6.8	7.4	6.4	4.9	3.8	2.1	54.8
Indianapolis	1.3	1.4	2.2	4.6	4.8	5.7	7.7	6.9	5.2	4.1	3.1	1.6	48.6
Cincinnati	1.8	1.8	2.6	4.9	5.2	6.4	6.5	6.6	6.1	4.7	3.3	2.1	52.0
Columbus	1.6	2.0	2.3	4.5	4.8	5.8	6.9	6.4	5.1	4.0	2.6	1.8	47.8
Pittsburg	1.4	1.9	2.2	3.8	4.2	5.4	6.6	5.6	4.9	3.4	2.8	2.3	44.5
Lower Lake Region.													
Buffalo	0.8	1.1	1.3	2.2	3.3	3.9	4.9	5.2	3.9	2.8	1.9	1.6	32.9
Oswego	0.6	1.0	1.1	2.2	2.8	3.8	3.9	4.0	3.6	2.7	2.2	1.0	28.9
Rochester	0.5	1.1	0.9	2.6	3.8	4.9	4.6	4.1	3.8	2.6	2.2	1.3	32.4
Erie	1.0	1.4	1.4	2.7	3.7	4.6	5.5	4.8	3.1	2.5	1.9	1.2	33.8
Cleveland	1.1	1.4	1.5	2.9	3.3	4.4	5.2	4.9	3.8	3.4	2.4	1.4	35.7
Sandusky	0.8	1.4	1.5	3.2	3.7	4.6	5.4	5.4	3.7	3.4	2.2	1.3	36.6
Toledo	0.9	1.1	1.5	3.5	3.8	4.6	6.0	6.4	3.7	3.4	2.4	1.3	38.6
Detroit	0.8	1.1	1.6	3.0	4.1	4.8	5.9	5.2	3.4	2.8	2.0	1.3	36.0
Upper Lake Region.													
Alpena	0.7	0.6	0.9	1.6	2.1	3.6	3.8	3.7	2.8	2.2	1.5	0.8	24.3
Grand Haven	0.5	0.7	1.3	2.6	3.1	3.8	4.7	3.8	2.7	2.6	1.7	1.1	28.6
Lansing	0.6	1.2	1.4	2.7	2.8	4.0	4.3	3.9	2.4	1.9	1.4	1.0	27.6
Marquette	0.8	0.8	0.9	1.7	2.4	3.3	3.4	3.3	3.1	2.2	1.3	1.3	24.5
Port Huron	0.6	1.0	1.1	2.6	3.0	3.8	4.6	4.2	3.2	2.5	1.7	1.0	29.3
Chicago	1.0	1.2	1.8	3.2	3.3	4.8	5.4	5.3	4.1	3.2	2.3	1.2	36.8
Milwaukee	0.5	1.0	1.1	2.4	2.6	3.8	4.8	3.7	3.4	2.9	1.9	0.9	29.0
Green Bay	0.5	0.6	0.8	1.7	2.5	4.1	5.6	4.2	3.0	2.4	1.9	0.9	28.2
Duluth	0.5	0.5	0.6	1.5	2.4	2.5	3.9	3.4	3.0	2.5	1.2	1.0	23.0
Extreme Northwest.													
Moorhead	0.2	1.4	0.5	2.1	3.6	3.8	3.7	3.3	3.5	2.4	1.3	0.5	26.3
Saint Vincent	0.3	0.3	0.5	1.8	3.8	3.9	3.1	2.6	2.6	2.0	0.9	0.3	22.1

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL-SERVICE STATIONS—*Continued*

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
Extreme Northwest.													
Bismarck	0.4	0.6	0.6	3.0	4.3	4.1	5.6	4.2	4.0	2.6	1.2	0.4	31.0
Fort Buford	1.4	0.7	0.6	3.0	4.7	5.0	6.2	4.9	4.8	3.0	1.7	0.5	35.5
Fort Totten	0.2	0.3	0.4	2.2	4.6	3.8	4.2	3.7	3.7	2.3	1.4	0.4	27.2
Up. Mississippi Val.													
Saint Paul	0.7	0.7	2.2	2.0	2.3	4.1	5.0	3.7	2.8	2.4	1.5	0.7	28.1
La Crosse	0.4	1.2	1.4	3.3	3.5	4.4	5.4	4.7	3.0	3.0	1.8	0.8	32.9
Davenport	0.5	1.0	1.8	3.8	3.4	4.6	6.9	6.2	4.4	3.0	2.3	1.1	39.0
Des Moines	0.6	1.0	1.5	3.7	3.1	4.2	6.6	4.7	4.1	3.3	2.3	0.9	36.0
Dubuque	0.7	1.0	1.4	2.2	2.9	4.2	6.2	4.8	3.3	2.8	1.8	0.9	33.2
Keokuk	0.8	1.1	2.1	4.2	3.7	4.3	7.0	6.8	5.0	3.8	2.9	1.2	42.9
Cairo	1.6	2.1	2.9	5.8	4.4	4.3	5.6	6.5	5.1	4.5	3.8	2.3	48.9
Springfield, Ill	0.8	1.1	2.0	4.6	3.8	4.3	5.4	6.5	4.5	3.5	2.9	1.4	40.8
Saint Louis	1.3	1.6	2.5	5.5	4.7	5.0	7.5	8.0	5.9	4.9	3.9	1.4	52.2
Missouri Valley.													
Lamar	1.1	1.6	2.4	4.4	3.8	4.0	6.0	4.6	3.7	3.6	2.9	1.5	39.6
Springfield, Mo	1.1	1.7	2.4	5.0	4.8	4.0	5.0	3.4	3.4	3.5	3.1	1.4	38.3
Leavenworth	0.9	1.5	2.3	4.6	4.5	5.0	6.3	4.5	4.0	3.9	2.7	1.4	41.6
Topeka	1.1	1.2	2.0	4.0	4.1	4.1	6.3	3.5	3.2	3.0	2.2	1.4	36.1
Omaha	0.8	1.5	1.4	4.4	3.8	5.2	6.2	5.2	4.3	4.3	3.0	1.4	41.7
Crete	0.7	1.1	1.2	3.5	3.3	4.5	5.6	4.7	3.8	3.6	2.4	1.1	35.5
Valentine	1.2	1.6	1.8	5.0	3.2	5.3	6.9	5.0	5.2	3.8	3.3	1.5	43.8
Fort Sully	0.6	0.9	1.3	4.4	4.1	5.2	7.7	4.9	5.7	3.6	2.8	0.7	41.9
Huron	0.3	0.7	0.8	3.7	3.7	4.1	5.7	4.2	4.1	3.1	2.4	0.7	33.0
Yankton	0.4	1.4	1.2	3.3	3.1	4.4	4.6	3.7	2.9	3.0	2.2	0.8	31.0
Northern Slope.													
Fort Assiniboine	0.8	1.2	1.2	3.8	4.1	4.2	6.8	5.5	4.8	3.5	2.5	1.1	39.5
Fort Custer	0.6	1.5	1.3	5.4	6.8	4.9	9.6	8.0	6.1	3.4	2.9	1.5	52.0
Fort Maginnis	1.1	1.4	1.1	3.3	3.2	4.6	6.8	4.6	3.8	2.8	2.0	1.1	35.8
Helena	1.1	3.6	2.1	6.1	4.3	5.5	7.2	7.7	6.4	4.3	3.0	2.1	53.4
Poplar River	0.4	0.8	0.8	2.7	4.9	5.7	6.0	4.8	4.4	2.5	1.7	0.7	35.4
Cheyenne	3.3	5.7	4.0	8.2	5.2	10.4	8.0	7.7	8.6	5.8	6.1	3.5	76.5
North Platte	0.8	1.8	1.8	5.4	3.9	6.9	6.0	4.8	3.7	2.8	2.3	1.1	41.3
Middle Slope.													
Colorado Springs	3.0	3.3	4.1	6.7	5.6	4.3	6.7	7.2	6.8	4.6	4.2	2.9	59.4
Denver	2.8	3.7	3.5	7.6	5.8	10.5	8.3	8.5	6.1	4.9	4.2	3.1	69.0
Pike's Peak	2.1	1.3	1.5	2.1	1.8	1.9	3.0	4.0	3.0	2.3	2.8	1.0	26.8
Concordia	1.3	2.8	1.8	4.8	4.3	5.7	7.3	5.2	4.3	4.5	3.4	1.8	47.2
Dodge City	1.4	2.4	2.8	4.1	4.6	7.4	8.3	6.6	5.5	5.2	4.2	2.1	54.6
Fort Elliott	1.3	1.9	3.2	5.1	5.4	8.2	7.6	6.2	5.4	4.7	4.2	2.2	55.4
Southern Slope.													
Fort Sill	1.6	2.0	2.6	3.8	4.0	4.4	4.8	7.5	5.1	4.2	4.1	2.0	46.1
Abilene	1.8	1.7	3.1	4.2	5.0	5.8	9.5	7.5	6.2	4.5	3.4	1.7	54.4

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL-SERVICE STATIONS—*Continued*

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
Southern Slope.													
Fort Davis	5.4	5.7	6.7	8.5	11.0	12.0	11.4	9.0	5.9	5.2	5.7	4.9	96.4
Fort Stanton	3.9	3.9	5.2	7.3	9.5	10.9	9.4	11.6	3.9	4.0	3.6	3.8	76.0
Southern Plateau.													
El Paso	4.0	3.9	6.0	8.4	10.7	13.6	9.4	7.7	5.6	5.2	4.6	2.9	82.0
Santa Fe	3.0	3.4	4.2	6.8	8.8	12.9	9.2	9.8	6.6	6.7	5.7	2.7	79.8
Fort Apache	2.6	3.0	3.6	6.8	9.4	9.1	7.1	6.7	5.3	5.2	4.1	2.6	65.5
Fort Grant	5.2	4.8	6.4	9.2	10.2	13.8	12.4	10.5	9.0	7.9	7.2	4.6	101.2
Prescott	1.4	2.8	3.6	5.4	6.2	8.1	6.6	6.5	4.7	4.9	3.6	2.2	56.0
Yuma	4.4	5.2	6.6	9.6	9.6	12.6	11.0	10.2	8.2	8.2	5.5	4.6	95.7
Keeler	3.0	4.6	6.3	8.7	9.3	11.9	12.8	13.9	10.6	8.8	5.9	4.8	100.6
Middle Plateau.													
Fort Bidwell	0.8	1.8	1.8	4.6	5.2	4.0	8.8	8.1	5.0	4.6	2.4	1.3	48.9
Winnemucca	0.9	2.8	6.2	9.1	9.3	10.1	11.5	12.0	9.9	6.6	3.7	1.8	83.9
Salt Lake City	1.8	2.7	3.6	7.2	6.9	8.9	9.2	10.7	9.6	6.5	5.0	2.3	74.4
Montrose	1.8	2.7	3.7	6.2	7.0	11.1	10.2	8.3	6.9	5.2	3.4	2.0	68.3
Fort Bridger	1.6	2.5	2.7	4.3	4.3	6.5	7.7	6.8	5.6	4.2	5.2	4.7	56.1
Northern Plateau.													
Boise City	1.6	2.5	3.8	6.1	6.5	6.6	10.0	9.2	7.4	5.2	3.2	1.8	63.9
Spokane Falls	0.7	1.7	2.7	4.4	5.4	4.4	7.7	6.4	3.8	2.5	1.7	1.4	42.8
Walla Walla	1.1	2.9	3.6	6.2	7.7	5.7	9.9	7.9	5.1	3.4	1.8	2.4	57.7
North Pacific Coast.													
Fort Canby	1.2	1.1	1.8	2.1	2.8	2.3	1.8	2.9	1.8	1.8	1.5	0.9	21.1
Olympia	1.3	1.2	1.8	2.5	4.1	3.3	3.2	3.1	2.4	1.5	1.3	1.1	26.8
Port Angeles	1.0	0.9	1.8	1.8	2.5	2.1	2.1	1.8	1.5	1.2	1.3	1.1	19.1
Tatoosh Island	1.2	1.1	1.8	1.4	1.8	1.8	1.4	1.4	1.4	1.6	1.8	1.4	18.1
Astoria	1.1	1.0	1.6	2.1	3.0	2.7	3.0	2.9	2.6	2.3	1.8	1.2	25.3
Portland	0.9	1.1	2.4	3.4	5.0	3.2	5.4	4.2	3.4	2.7	1.8	1.2	34.7
Roseburg	1.2	1.6	2.7	3.9	4.7	3.5	5.4	4.7	5.0	3.2	1.7	1.6	39.2
Middle Pacific Coast.													
Red Bluff	3.0	4.6	5.4	6.1	7.0	6.9	11.0	10.7	10.1	10.5	5.9	3.6	84.8
Sacramento	1.8	3.1	3.7	4.3	4.2	5.6	5.9	5.6	6.5	7.3	3.9	2.4	54.3
San Francisco	2.7	2.7	3.3	3.1	2.8	3.1	2.4	2.5	3.3	5.0	2.8	3.0	36.7
South Pacific Coast.													
Fresno	1.8	2.8	3.0	5.6	6.0	7.0	9.1	10.2	7.6	6.7	3.8	2.2	65.8
Los Angeles	2.3	2.0	2.8	3.4	3.0	3.8	3.2	3.5	3.1	4.1	3.0	3.0	37.2
San Diego	2.9	2.7	2.5	2.7	3.3	2.8	3.2	3.3	2.9	4.3	3.2	3.7	37.5

be taken into the ground. This is not mere theory; it is based on observations made during many days spent in the forest, and is believed to almost, if not fully, account for the better sustained flow of forest streams and their lighter flood-flows."

The official chart and figures found on pages 285 to 289 showing depths of evaporation are from the United States Weather Service Report:

Evaporation takes place from both ice and snow. Its amount is appreciable even below 10° F. and it increases rapidly with rise of temperature.

This fact is shown graphically by A. F. Meyer in his comprehensive paper on " Computing Run-off from Rainfall and other data." *

The flow of streams depends upon causes quite various in character, such as deep-seated springs, melting of glaciers (e.g., the River Rhone), and other unusual sources, but for the great majority of cases the flow is traceable directly to the rainfall run-off and to springs of local origin.

In Kicking Horse Valley, British Columbia, the streams shrink on rainy days and swell on those of sunshine for the reason that rainfall does not compensate for the lack of the melting snow.

What is the amount of the *run-off* to be expected per square mile of watershed is essentially a local question, not one to be formulated generally for widely separated localities.

Fanning believes that for ordinary watersheds it is fair to assume that 50 per cent of the annual rainfall flows off in the streams.

More in detail, it is as follows:

Mountain slope or steep rocky hills	80 to 90	per cent
Wooded swampy lands	60 to 80	"
Undulating pasture and woodland	50 to 70	"
Flat cultivated lands and prairie	45 to 60	"

He also considers the " low rain-cycles " mean rainfall to be about 80 per cent of the general mean rainfall.

From the report of the committee on yield of drainage areas, J. N. E. Water-works Asso., Dec. 1914, we note the following comparison of run-off, upon sundry eastern watersheds, in years of high and low precipitation:

* Am. Soc. C. E., 79: 1079.

	Average Precipitation (Inches)	Average Run-off (Inches)	Per cent of Run-off
Highest 20 years.....	56.29	30.00	53.3
Lowest 20 years.....	39.29	16.92	43.1

It is to be observed that when the precipitation is high the percentage of it that passes into the run-off is much higher than that which follows a smaller amount of rainfall.

An examination of the data secured by the same committee permits of the conclusion that, as a fair average of the Eastern watersheds considered by them the land surface will yield for storage about one million gallons per square mile per day.

According to the U. S. government reports, "for the area of the United States east of the ninety-fifth meridian the run-off is from 35 to 50 per cent of the total rainfall. It appears to be largest in the vicinity of the Great Lakes, and diminishes from this region slowly to south and east, and rapidly towards the west. In the lower peninsula of Michigan, for instance, the run-off is 50 per cent of the total rainfall. Along the Gulf coast it appears to be only from 30 to 40 per cent, and along the Atlantic coast it probably varies from 30 to about 50 per cent. In general, for the interior States east of the ninety-fifth meridian the run-off is between 40 and 50 per cent of the total rainfall.

"As soon as we cross the ninety-fifth meridian westward we find a very sharp fall in the percentage of run-off to the total rainfall. For the band extending north and south between the ninety-fifth and one hundred and fifth meridians this percentage varies from 10 to 25 per cent, and over Iowa is about 33 per cent. The percentage is highest at the northern end of the band indicated, and lowest at the southern end. Going still farther westward we come to another very marked area, that of the Continental Divide; here the percentage of run-off suddenly increases, reaching the highest figure to be found in the United States. From Montana to Colorado it varies from 60 to 70 per cent of the total rainfall. In New Mexico it falls to about 33 per cent. This evidently on account of the easy flow of water from the mountain ranges in the

area in question. West of the Divide the run-off is again small, being only 15 or 20 per cent in Arizona and Nevada, about 30 per cent in Idaho, and nearly 50 per cent in Utah. Utah, it seems from its topography, partakes of the character of the band lying just to the east of it. Along the Pacific coast the run-off is about 25 per cent in Oregon, 30 per cent in Washington, and between 45 and 50 per cent in California.

"In general we may say that the run-off on the more level areas of the United States is less than 50 per cent, and on the great plains may fall as low as 10 per cent. In the mountain regions it may rise to as high as 70 per cent. In the relatively dry area, or the areas of distinctly dry seasons, the percentage is very much reduced." * The "run-off" for the State of Connecticut is placed at 60 per cent of the rainfall.

The watershed of the new Scituate reservoir to supply Providence, R. I., has a rainfall of forty-five inches annually and a run-off of twenty-one inches, or 47 per cent. Since twenty-one inches of yearly rainfall practically equals one million gallons per square mile per day, we note the probable daily yield for storage per square mile to be about one million gallons.

The following figures have been taken from official sources:

RAINFALL AND RIVER-FLOW FOR THE CONNECTICUT RIVER BASIN

Month.	Average Rain in Inches.	River-flow in Inches On Whole Watershed.	Per Cent of River-flow to Rainfall.
January	3.27	1.93	59.1
February	3.10	2.04	65.8
March	3.94	3.00	76.3
April	3.26	4.73	145.0
May	3.17	4.19	132.2
June	4.00	1.46	36.5
July	4.79	1.02	21.3
August	4.87	1.06	21.8
September	3.04	0.89	29.3
October	3.93	1.11	28.3
November	3.93	1.76	44.8
December	3.39	2.06	60.7
	44.69	25.25	56.5

* "The point at which a region may be classed as arid and unfit for successful agriculture without irrigation should be lowered, it is believed, to 15 inches annual rainfall." (Report of Chief Signal Officer, 1880.)

RAINFALL AND RIVER-FLOW FOR THE POTOMAC RIVER BASIN

Month.	Rainfall in Inches.	River-flow in Inches.	Per Cent of River flow to Rainfall.
January	3.21	2.09	65.2
February	3.35	3.36	100.1
March	4.39	3.62	82.6
April	3.48	3.51	101.0
May	5.11	2.36	46.3
June	5.25	1.93	36.8
July	4.89	1.00	20.5
August	3.81	0.78	20.5
September	3.86	1.06	27.5
October	2.65	1.21	45.7
November	2.88	1.79	62.3
December	2.59	1.32	51.1
	45.47	24.03	53.0

Rafter in "Water Supply and Irrigation Papers No. 80, U. S. Geological Survey," gives yearly average data for twelve drainage basins in the eastern part of the United States, as follows:

Drainage Basins.	Years of Record.	Rainfall, Inches.	Run-off, Inches.	Evaporation, Inches.
1. Muskingum River, Ohio	1888–1895	39.7	13.1	26.6
2. Genesee River, N. Y.	1890–1898	40.3	14.2	26.1
3. Croton River, N. Y.	1877–1899	49.4	22.8	26.6
4. Lake Cochituate, Mass.	1863–1900	47.1	20.3	26.8
5. Sunbury River, Mass.	1875–1900	46.1	22.6	23.5
6. Mystic Lake, Mass.	1878–1895	44.1	20.0	24.1
7. Neshaminy Creek, Pa.	1884–1899	47.6	23.1	24.5
8. Perkiomen Creek, Pa.	1884–1899	48.0	23.6	24.4
9. Tohickon Creek, Pa.	1884–1898	50.1	28.4	21.7
10. Hudson River, N. Y.	1888–1901	44.2	23.3	20.9
11. Pequannock River, Conn.	1891–1899	44.2	26.8	20.0
12. Connecticut River, Conn.	1872–1885	43.0	22.0	21.0

It must be added, however, that Mr. Rafter insists upon the danger of depending too much upon "average" results in such matters. He says, "What is wanted is a clear state-

ment of the minimum, together with the longest period which such minimum may be expected to occupy."

As a matter of fact all run-off statistics should be used with much care. Mr. T. U. Taylor has well said:

"Any attempt to apply run-off data obtained in one section of the country to a locality or stream in another section is full of the utmost danger. The regularity of flow, the quantity of daily flow, the mean monthly flow, the mean annual flow, and the run-off are data that can be obtained only by careful observations and measurements for the locality, station, and stream concerned. The run-off for the same stream, at different stations along its course, will be found to vary greatly.

"Run-off is a complex factor, depending on topography, vegetation, kinds of soil (whether cultivated or uncultivated), rainfall, distribution of rainfall as to time of year and as to growth of vegetation, and, what is still more vital, the condition of the soil at the time of the rains. Personal observation has convinced me that a two-inch rainfall in twenty-four hours may at one time give a run-off of 25 per cent and at another time no run-off whatever." *

A curious instance of a most unbalanced relationship between rainfall and run-off was reported some years ago.† It seems that in the Painted Desert, Ariz., a copious shower of rain was observed to fall toward the earth, but it became entirely evaporated as it fell and never reached the surface of the ground.

Where conditions are exceptionally favorable for percolation none of the run-off may reach living streams.

G. Lidy ‡ uses the following equation:

$$P+E+R=R',$$

where P is the percolating water entering the soil; E the water

* Am. Soc. C.E., 40: 166.
† J. Fk. Inst., Apr., 1904.
‡ "La Technique Sanitaire," p. 145, 1910

which evaporates directly from the surface; R the run-off, and R' the rainfall.

The latest German value obtained for $P+R$ is .4 to .5 of the value of R', the value of E being at least .8 of R'. These values leave the above equation unbalanced, the first member being larger than the second. Lidy considers that the difference between the two members is caused by an increased value of P due to atmospheric moisture condensed directly in the pores of the soil from the air which circulates therein. Moisture from such a source is, of course, not a portion of the rainfall. That it may amount to something noteworthy in volume is shown by Lidy's experiments.

A good map showing the "run-off" for the United States will be found in the 14th report of the U. S. Geological Survey, Part II, page 150.

Even with uniformity in rainfall the rate of river-flow must vary, owing to such disturbing factors as frozen ground in winter and excessive evaporation in summer.

For Eastern Massachusetts Mr. Desmond FitzGerald places the months in order of dryness, averaging as follows:

1. July.	4. June.	7. May.	10. April.
2. September	5. October.	8. December.	11. February.
3. August.	6. November.	9. January.	12. March.

Showing the wettest months to be the first four in the year.

INFLUENCE OF FOREST UPON WATER SUPPLY

Do forests change climate; do they increase rainfall; do they have any effect upon floods; do they conserve water supply?

Many writers, official and otherwise, have undertaken to answer these questions and have done so in fashions so various that the ordinary man is forced to fall back upon his own resources and attempt the answers for himself.

A part of the following is freely condensed and extracted from the government report upon "Forest Influences," issued by B. E. Fernow, Chief of the Forestry Division.

Transpiration occurs through the leaves of trees as it does through those of smaller vegetable growths and a considerable part of the water falling as rain upon a forest is returned to the atmosphere by such action.

During the period of vegetation the following varieties transpire per pound dry weight of leaves:

	Pounds of Water
Birch and linden	600–700
Ash	500–600
Beech	450–500
Maple	400–450
Oak	200–300
Spruce and Scotch pine	50–70
Fir	30–40
Black pine	30–40

Conifers transpire one-sixth to one-tenth of the amount which is needed by deciduous trees.

The transpiration from leaves in full sunshine is decidedly greater than from leaves in the diffused daylight or darkness. The absolute amount of annual transpiration as observed in forests of mature oaks and beeches in Central Europe is about one quarter of the total annual precipitation.

Raphael Zon * of the U. S. Forest service quotes data obtained from the Mariabrunn (Austria) forest experiment station which show that "one acre of oak forest, 115 years old, absorbed in one day from 2227 to 2672 gallons of water per acre, which corresponds to a rainfall of from 0.09 to 0.115 inch per day, or 2.9 to 3.9 inches per month. Taking the period of vegetation as five months, the absorption of water would be 158,895 cubic feet, which represents a rainfall for this period of 17.7 inches. This amount of water is given off merely through transpiration from the leaves and does not include the physical evaporation from the surface of twigs, branches, and leaves. These figures, while only approximate, give an idea of the enormous quantities of water given off by forests

* Science, July 18, 1913.

into the air. It may be compared to clouds of exhaust steam thrown into the atmosphere."

Evaporation from the ground in the forest is naturally much less than in the open fields.

The forest cover, and especially the litter of a well-kept forest, may decrease the amount of evaporation within the forest to nearly seven-eighths of that in the open. The reason for this important influence of the forest is due not only to the impeded air circulation, but also the temperature and moisture conditions of the forest air and forest soil.

It is this protection against evaporation which gives to the forest one of its chief values as a guardian of water supply. The forest floor, with its irregularities and its sponge-like qualities, moreover, stops the rapid and ruinous draining of the surface, with possible denuding of the land and favors slow percolation through the soil and reinforcement of the springs.

The influence of forest cover upon the flow of springs is due to reduced evaporation, as well as to the fact that by the protecting cover the soil is kept granular and allows more water to penetrate and percolate than would otherwise be the case. The condition of the forest floor is of great importance. Where the litter and humus mold is burned up, as in many of our mountain forests, this favorable influence is largely destroyed although the trees are still standing.

In consequence of deforestation evaporation from the soil is augmented and accelerated, resulting in unfavorable conditions of soil humidity and affecting unfavorably the size and continuity of springs.

Inasmuch as a low growth of " saplings " may cover a former forest floor very quickly, it is difficult to be sure that recent data, supposed to be furnished by " de-forested " areas, truly represent the relation between forest and stream flow on the one hand and cleared land and stream flow on the other.

Snow is held longer in the forest and its melting is retarded, giving longer time for filtration into the ground, which also,

being frozen to lesser depth, is more apt to be open for subterranean drainage. Altogether forest conditions favor, in general, greater subterranean and less surface drainage, yet the moss or litter of the forest floor retains a large part of the precipitation and prevents its filtration to the soil, and thus may even diminish the supply to springs. This is especially possible with small precipitations.

Although the quantity of water offered for drainage on naked soil is larger, and although much is utilized by the trees in the process of growth, yet the influence of the soil-cover in retarding evaporation and run-off tends to offset this loss, as the soil-cover is not itself dried out.

Naturally, a saturated forest floor can absorb no further amount of water, therefore the run-off from excessive rainfall, or rapid melting of snow, must pass to the streams as quickly as in a cleared district, but the temporary retention of a large amount of water and its eventual partial deflection into subterranean drainage, with consequent lengthening in the time of flow, would at least tend to reduce the number and height of regular floods.

Floods due to special and unusual causes, such as that of the upper Hudson River Valley in March, 1913, cannot be guarded against. Upon that occasion excessive, long-continued rain fell upon a deeply frozen soil devoid of snow. The run-off was, of course, like that from a roof.

The New York Forest Commission, speaking of floods in the Adirondack region and the influence of forests in relation to them, says:

"In the uplands of the preserve there are many densely wooded tracts adjacent to others from which the forests have been stripped. The residents agree that in the former floods are unknown, while in the latter they are a yearly occurrence. Their appearance was coincident with the disappearance of the woods. It was then noticed that the bridges, which for many years had sufficed to span the streams during heavy rains, were no longer safe, and new ones with longer spans became a necessity."

They refer also to the effect of the removal of the forests in the Adirondack watersheds upon the navigation of the canals of the State and the whole system of inland commerce.

Placing reliance upon the testimony of "the oldest inhabitant" involves considerable risk, and is often met by such records as the following.* Translation by W. L. Moore.

Dates of the Inundations of the Seine Valley.	Height at the Bridge of La Tournelle. Feet.	Mean per Half Century. Feet.
July 11, 1615	29.99	27.53
January, 1649	25.10	
January, 1651	25.59	26.36
March 1, 1658	28.87	
March, 1690	24.61	
March, 1711	24.77	25.34
December 25, 1740	25.92	
January, 1751	21.98	22.42
November 14, 1764	22.97	
March 4, 1784	21.85	
February 4, 1799	22.87	
January 3, 1802	24.44	21.22
March 3, 1807	21.85	
May, 1836	18.66	
February, 1850	19.91	

"The deductions from this table are striking. The continued decrease of the floods for each half century is remarkable. The waters attained a mean height of 27.53 feet in the first half of the seventeenth century; they only attained a mean of 21.22 feet in the present. According to this, we have experienced an amelioration of nearly 6.56 feet, and yet the trees have been steadily and unceasingly cut down, and the forests transformed into cultivated farms."

Before being convinced by the above we must however remember that the most disastrous flood that the valley of the Seine ever experienced occurred in 1910.

As to actual aid in the *production of rain-fall* it must be admitted that it is hard to gather together numerical facts that show the forest to be of material value; but as a scientific

* Annales des Ponts et Chaussées, 1852, p. 102.

proposition the following point raised by Dr. Raphael Zon * is worthy of careful attention.

"While direct evaporation from the ground not sheltered by forest-cover may become greater, yet the more rapid run-off and the absence of transpiration by trees would necessarily reduce the total amount of water evaporated into the atmosphere. The land, were it even taken up for agriculture, would not return such large quantities of rain into the atmosphere as the forests did. The inevitable result would be that less moisture would be carried by the prevailing winds into the interior of the country, and therefore less precipitation would occur there. The destruction of forests, especially if it leaves the ground bare or partly covered with only weak vegetation which does not transpire large quantities of water, must inevitably affect the climate, not so much the climate of the region in which the destruction took place but the drier regions into which the prevailing air-currents flow."

Finally, after having weighed what many writers have written, the preponderance of evidence seems to show that the forest acts as a "governor" of stream flow, rather than as a means of increasing precipitation.

Erosion following forest destruction may be due to either wind or water, and may be great or small, depending upon climate, depth and character of the exposed soil and its slope.

Col. H. M. Chittenden in a very full paper † claims that "soil erosion does not result from forest cutting in itself, but from cultivation, using that term in a broad sense."

Such a conclusion will certainly not hold true in all districts, for instance in the Canadian locality shown on page 301. The photograph was kindly sent the author by Mr. Elwood Wilson of Grand Mère, P. Q.

Having once carefully selected a watershed, it should be protected with the greatest care which science suggests, and

* Science, July 18, 1913.

† Proc. Am. Soc. C.E., Sept., 1908.

SHOWING EROSION FOURTEEN YEARS AFTER REMOVAL OF THE TIMBER.

with the utmost vigor which the law allows. Right here is the weakness shown by many of our city councils. The law is strong enough, and the municipal rights are plenty, but it is often very difficult to move the authorities to proper action. A most fruitful source of evil arises from the unquestioned right of a riparian landholder to "water his stock." The broad interpretation of this right can be carried to an absurd degree; for instance, the writer has seen the open channel-way connecting the storage and distributing reservoirs of a large city doing duty, at one point of its course, as a farmyard drain, the cattle standing in the small stream at pleasure.

It may not be amiss to point out that regulations for the protection of a watershed which do well enough during summer months may entirely fail of effectiveness after the ground becomes frozen. Drainage material which at one time could sink into the ground and become oxidized by infiltration would at other seasons flow down steep slopes over the frozen surface, or, if itself arrested by frost, would be at a latter date washed into the stream by melting snows over the yet unthawed ground. Such cases of contamination are not rare, and may be followed by most serious consequences, as was instanced by the outbreak of typhoid fever at Plymouth, Pa. It is useless to depend upon the purifying action of frost, for, as has been shown, typhoid germs can withstand being frozen in solid ice during a considerable period.

As further reasons why winter conditions may increase the danger due to a polluted water, let it be noted that: Adverse organisms are fewer; sunlight is weaker; viscosity of the water being greater the sedimentation is slower; and the temperature of the water being lower conduces to greater typhoid longevity.

To repeat what we have already touched upon, the purifying action of filtration through common soil is a point frequently misunderstood, and yet of important bearing when considering the protection of a watershed. Such filtration is only effective when it is intermittent.

The nitrifying organisms which accomplish the oxidation

of the objectionable sewage material can only operate in presence of atmospheric oxygen. A supply of air must be present in the pores of the soil or else oxidation ceases. After a " dose " of sewage has been applied to a soil a sufficient interval must elapse to permit the air to renew the exhausted oxygen; otherwise the slow-moving and continuous stream of filth must carry its objectionable properties to considerable distances.

How important, then, that every privy located within drainage distance of a source of water supply should be built without a vault, and should have its cleanings removed at frequent intervals and disposed of in a safe manner.

Finally, however desirable for the moment a river may be as a source of water supply, it must not be forgotten that the conditions may change in the course of years with the growth of population up-stream, as has been already noted on another page. Objection is properly raised to the use of the unfiltered water of a large river, on the ground that pollution of the stream by sewage material is certainly on the increase, and that the introduction of sewage systems in the towns above will, at no distant date, render the river-water very undesirable.

It has to be admitted that the water of even a mountain stream, if taken in the raw state, might readily prove itself more objectionable than that of a large though polluted river, if the latter were efficiently filtered before delivery to the consumers, for the reason that three or four families on the small stream might, unknown to the city authorities, chance to have their privies and drains empty directly into the brook without soil intervention.

Further consideration of care of water sheds will be found under " stored water."

CHAPTER VII

STORED WATER

NATURE provides enormous quantities of water stored up in lakes and ponds ready for human consumption, and man frequently supplements this provision by impounding waters in artificial basins when the natural reservoirs of the district are unavailable or are insufficient in size. Some of these artificial lakes are of great extent, thus the Ashokan reservoir for New York City has an area of about thirty-six square miles with an average depth of fifty feet. Still larger are the St. Maurice Reservoir (Quebec), capacity 160 billion cubic feet; Gatun Lake (Panama), capacity 183 billion cubic feet; and the reservoir at Assuan (Egypt), 3750 billion cubic feet.

Lakes of such great size as to be properly considered inland seas—the Great Lakes of North America, for instance—furnish water of quite constant composition, free from the considerable vegetable contamination so frequently met with in small lakes and ponds.

	Lake Superior, near Duluth, 40 Miles Out from Shore. March, 1896.	Lake Michigan* 12 miles out from Chicago. Oct. 23, 1896.	Lake Erie, near Erie, Pa., 14 miles out from Shore. October, 1897.
Free ammonia	.03	0.0	.045
Albuminoid ammonia	.02	.08	.112
Chlorine	2.	5.5	3.5
Nitrogen as nitrates	.00	0.0	.08
Nitrogen as nitrites	0.0	0.0	trace
Required oxygen	1.15	1.6	1.25
Total solids	54.	130.	134.

* "Streams Examination," p. 18.

MINERAL ANALYSES OF WATERS OF THE GREAT LAKES *

(Average of 10 or more analyses for each (by Dole)

PARTS PER MILLION.

	Superior.	Huron.	Michigan.	Erie.	River St. Lawrence.
Samples taken at	Sault Ste. Marie.	Port Huron.	St. Ignace.	Buffalo.	Ogdensburg.
Turbidity	2.	tr.	tr.	41.	4.5
Silica (SiO_3)	7.4	12.	10.	5.9	6.6
Iron (Fe)	.06	.04	.04	.07	.05
Calcium (Ca)	13.	24.	26.	31.	31.
Magnesium (Mg)	3.1	7.	8.2	7.6	7.2
Sodium and potassium (Na+K)	3.2	4.4	4.7	6.5	6.3
Carbonates (CO_3)	0.0	1.8	2.9	3.1	2.9
Bi-carbonates (HCO_3)	56.	100.	112.	114.	116.
Sulphates (SO_4)	2.1	6.2	7.2	13.	12.
Nitrates (NO_3)	.5	.4	.3	.3	.3
Chlorides (Cl)	1.1	2.6	2.7	8.7	7.7
Total solids	60.	108.	118.	133.	134.
Total hardness (calculated)	45.4	89.2	99.2	108.2	107.5

Large as these Great Lakes are, the influence of the sewage from cities upon their shores is nevertheless beginning to be seriously felt. The pollution of Lake Michigan by the sewage of Chicago is a widely known fact, and the intakes, situated as they are one to five miles from shore, are frequently reached by the ever swelling volume of the city's refuse.

It was with the object of preventing the pollution of Chicago's water supply that the Chicago Drainage Canal was constructed, whereby the current of the Chicago River was reversed and the city's sewage was washed into the Mississippi valley by water from Lake Michigan.

"The canal was put in operation in January, 1900. It was designed to have a capacity of 10,000 cubic feet per second, with a velocity of 1.25 miles per hour in earth and 1.9 mile per-hour in rock. The capacity was based on the assumption that in order to prevent nuisance it was necessary to dilute the sewage to the extent of providing $3\frac{1}{3}$ cubic feet per second for each 1000 persons discharging sewage into the canal.

* J. N. E. Water Works Assn., 23: 259

"The canal has a total length of 28.05 miles and a minimum water depth at low stage of Lake Michigan of 22 feet. The rock section is 15.95 miles long, 160 feet wide at the bottom and 162 feet wide at the top. A portion of the earth section, 5.3 miles long, is 202 feet wide at the bottom and has side slopes of 2 to 1. The remainder of the canal, also in earth, is 7.8 miles long, and as originally built was 110 feet wide at the bottom, with side slopes of 2 to 1."

Effort has been made to have the amount of water abstracted from Lake Michigan increased, but the report of the International Waterways Commission was adverse to this movement, their recommendation being "that the Government of the United States prohibits the diversion of more than 10,000 cubic feet per second for the Chicago Drainage Canal."

Much opportunity is given in large lakes for sedimentation to come into full play, and settlement is, in consequence, a great item in the process of the natural purification of their waters.

So far as the American "Great Lakes" are concerned, there is a difference in this respect between Lake Erie and the other members of the group. Lake Erie is comparatively shallow and is stirred to its bottom by every gale, therefore sedimentation advantages therein are at a minimum.

Naturally the shallow water near the shore of a lake would show the greatest amount of bacterial life. It would also be expected that the advantage of sedimentation would be made more evident in the character of the water of the outlet than in that of an entering stream.

Dunant found 150,000 bacteria per cubic centimetre in water from Lake Geneva taken near the shore, and only 38 per cubic centimetre in a sample from the middle of the lake. Percy Frankland examined the waters of two inlets of Loch Lintrathen and found them to possess counts of 1700 and 780 per cubic centimetre respectively, while the outlet of the loch contained but 30 per cubic centimetre.

In smaller lakes and ponds the influence of vegetation begins

to be felt, sometimes so seriously as to interfere with the use of their waters for potable purposes, and we are confronted by the question, what, if any, are the advantages and disadvantages of reservoir storage.

Tersely stated, the advantages of water storage are many and the disadvantages but few. In those days when the expression "stagnant water" carried with it all sorts of ill-defined fears, the opponents of storage were easy to find, and their enthusiastic statement that "abundance of light and air is essential to the proper conditioning of water for human consumption" received very general support. He who drank of the rapid stream was accounted greater in wisdom than he who selected a less aerated supply.

It is now almost trite to say that still water, rather than running water, purifies itself the better, and it equally lacks novelty to point out that the more rapidly a stream flows, the sooner is its load of pollution delivered to the thirsty consumer. In that connection, let it be again said that a great deal more depends upon the number of hours required for stream-flow than upon the distance in miles between the intake and the source of pollution, and a concise statement giving information as to time of flow should appear in a report covering the sanitary survey.

Stagnation has its disadvantages, of course. Increase in color naturally follows if water be permitted to long remain in contact with a muddy bottom loaded with soluble extractive matters. Not only is damage to the water's physical appearance a result of such contact, but the material passing into solution is likely to furnish abundant food for those minute forms of life which carry objectionable tastes and smells to many public waters.

To the layman's ear the word "stagnant" has a most unpleasant sound, intimately associated with the production of disease; and yet its origin is innocent enough, viz., "stagnum," a piece of standing water, not running in a current or stream.

Pools so overloaded with vegetable growth, both dead and

alive, as to be unfit for human drinking are plenty and they are commonly stagnant, but the ill-favored word does not properly apply alone to those; it is just as applicable to a water of crystal clearness resting upon a bed of sand.

The condition of "standing water" just referred to,—namely, that of being overstocked with vegetable growths,—is practically the only one toward which objection can point when considering the *pros* and *cons* of reservoir storage.

The word "vegetable" is here to be taken in its broad sense, as it should include not only those growths which would be recognized by the public at large, but also those of the minute world as well, which latter constitute one branch of that lake life known as "plankton."

As one of many instances of excessive overgrowth, a small lake could be named which is so loaded with dense vegetation that decay gets ahead of new growth, and the use of its water is productive of temporary diarrhœa. It is a stained water, but its color is not to be considered as a measure of its objectionable qualities for table use, as many waters of much darker tint are of excellent quality for such purpose. Color and fitness for drinking bear no relation to each other.

It is true that colorless waters are now demanded by the people, and "meadow teas" are growing in disfavor, but that change in public opinion is of recent date and is not based upon sanitary considerations.

The deepening in color of the lower layers of a water stored upon an unclean bottom; the encouragement of growth of small organisms producing taste and smell by reason of an accumulation of extracted food suitable for their development; and a deficiency in dissolved oxygen in the bottom levels, constitute the sum of objections that can be raised to the impounding of water, and they are much more than balanced by the advantages that accrue from such storage.

Observations have been made by W. A. Manss of this laboratory, showing the influence of depth upon the character of water in a storage reservoir of about 3000 areas.

He found that during the summer season, owing to the

comparative lightness of the warmer water, no circulation takes place below a depth of twenty-five feet, that being the usual distance to which wind and wave agitation extends. Should a lake be protected from the wind, the aerated layer may extend temporarily from ten to forty feet from the surface, depending upon the extent of the water-surface, and below this level the cold, stagnant water rests, until such time as the chilling of the upper layer increases its gravity to and beyond that of the lower layer upon which it floats. When this point is reached, readjustment of relative position is immediately instituted, in accordance with the change in specific gravity, and the water of the lake " turns over."

The formation of this stagnant layer begins in April in this latitude, and circulation is partly re-established in October and completely so in November. With the advent of freezing weather a second period of stratification is inaugurated which continues until the surface thaws again in the spring. Vertical circulation then progresses until the warm sun of later April renders the surface-water so light as to float upon the colder layers beneath, when summer stagnation again begins.

Whenever the lower stagnant layer is brought in contact with the decomposing organic matter, as is the case in reservoirs with bottoms from which the vegetation has not been removed, the dissolved oxygen present is quickly used up; quantities of extractive matters pass into solution and the water acquires an odor and becomes dark in color.

Many analyses are available showing this diminution and ultimate total exhaustion of dissolved oxygen in the stagnant layer.

Even though the bottom of a lake or reservoir be perfectly clean and sandy, the dissolved oxygen must surely diminish to some extent in the lower layers of the water.

That the stagnation of water in the lower levels of a reservoir is not in itself objectionable has been shown by Dr. Drown in his study of reservoirs Nos. 3 and 4 of the Boston Water-works:

" Water in the stagnant layer does not become foul unless

there is decomposable organic matter present. Thus in Basin 4 of the Boston Water-works, which was carefully prepared for the reception of the water by the removal of all soil and vegetable matter, and is supplied with a brown, swampy water from a watershed almost entirely free from population, the water is good at a depth of forty feet, because the water contains very little organic matter with a tendency to decomposition.

RESERVOIR NO. 3, BOSTON WATER-WORKS (AUG. 20, 1891)

	Temperature, Deg. Fahr.	Per Cent of Dissolved Oxygen.
Surface	74.7	85.88
6 feet below surface	74.7	85.06
12 " "	70.9	58.97
14 " "	——	0
15 " "	——	0
17 " "	——	0
19 " "	——	0
21 " " (bottom)	62.8	0

RESERVOIR NO. 4, BOSTON WATER-WORKS (AUG. 20, 1891)

Surface	74.7	84.50
10 feet below surface	70.9	84.42
20 " "	61.9	28.02
30 " "		27.42
35 " "	54.7	16.28
36½ " " (bottom)	54.7	15.10

"The contrast in the condition of the water in these two reservoirs is very striking. Reservoir No. 3, in which the oxygen is exhausted at a depth of 14 feet, receives a not inconsiderable amount of direct pollution from the towns of Marlborough and Southborough, while the drainage-area of Reservoir No. 4, as has been already said, is very sparsely poplulated."

Uniform experience goes to prove that good water may be preserved in properly constructed reservoirs without deteriora-

tion for indefinite lengths of time. It must be remembered, however, in this connection, that to keep a ground-water in good condition it is necessary to cover the reservoir. Such waters are usually charged with mineral matter suitable for plant-food, and the growths of algæ will be very likely to appear therein unless light be excluded. Thus the great reservoirs supplying the spring-waters of Paris are kept entirely dark, with the best of results. Reservoirs used to store filtered surface-waters should be likewise covered for the same reason.

Algæ, and directly or indirectly the "plankton" in general, largely depend for their development upon material furnishing nitrogen. Water containing a moderate amount of this element washed from natural sources will sustain but a small growth of such life; but where nitrogen is present in great quantity as nitrates, as is the case in many deep-seated waters, the development of algæ is often excessive during storage, if light be admitted.

The effluent from a well-designed sewage-disposal plant would, if added to stored water, cause a heavier growth of algæ than would be produced by the raw sewage itself because of its containing a larger quantity of nitrates.

It must not be sweepingly assumed that all the "Plankton" life is to be rated as uniformly objectionable; quite the contrary, as a reasonable degree of it acts as a distinct help in maintaining the safety of natural waters. Thus we find "bacteria-eaters" such as many kinds of ciliated infusoria, rotifers, daphnia and the like, feeding upon minute germ life, and doing so to our great advantage.

To quote from a translation by Kuichling:

"The question is, what becomes of the great quantities of offal and excreta, the many remnants of decaying plants, the refuse of communities, and the finely divided factory wastes of every description, which find their way into our streams, even under normal conditions, if a large portion thereof is not consumed by the aquatic detritus-eaters and the omnivorous fauna before settling to the bottom."

An investigation by C. P. Hoover * shows that " Intestinal organisms will not live in water containing no free or half-bound carbonic acid.

Lime-softened water is fatal to bacteria of the colon and typhoid group in forty-eight hours. The action is selective in that certain harmless bacteria grow but the disease-producing germs do not."

As algal growths use up dissolved carbon dioxide it is evident that this form of plant life will act as a protection against such pathogenic bacteria as may find admission to storage reservoirs.

Experience indicates that storage of surface-waters in open reservoirs causes but little change in the character of such waters, and that what small change does take place is beneficial, but the bad effect of the open storage of ground-waters is quite strongly marked. No better illustration could be given of the different actions of surface and ground waters during similar conditions of storage in open reservoirs than to call attention to the results secured at Atlantic City, N. J. The two supplies of the city, although afterwards mixed, are stored separately in basins of about the same size, separated one from the other by an embankment only a few feet wide. See illustration on page 313. The water shown in the foreground is from flowing wells which deliver through the bottom of the reservoir. It is continually filled with large masses of green growth. The reservoir seen in the background holds surface-water, admitted by canal, and it is entirely free from vegetation of any kind. A more instructive instance of varied results under identical storage conditions could hardly be asked.

To put it tersely, it may be said that a water from a dark source should be stored in the dark and *vice versa*; filtered water being the exception, as above noted, and requiring dark storage irrespective of its source.

The chart on page 314 which graphically shows the temperature variations during the summer season for different depths of Lake Cochituate, was prepared by Desmond Fitz-

* *Engr. Record*, Sept. 6, 1913.

Gerald for the report of the Boston Water-works. It will be noted that the temperature curves run together at the times of the semi-annual " turn-over."

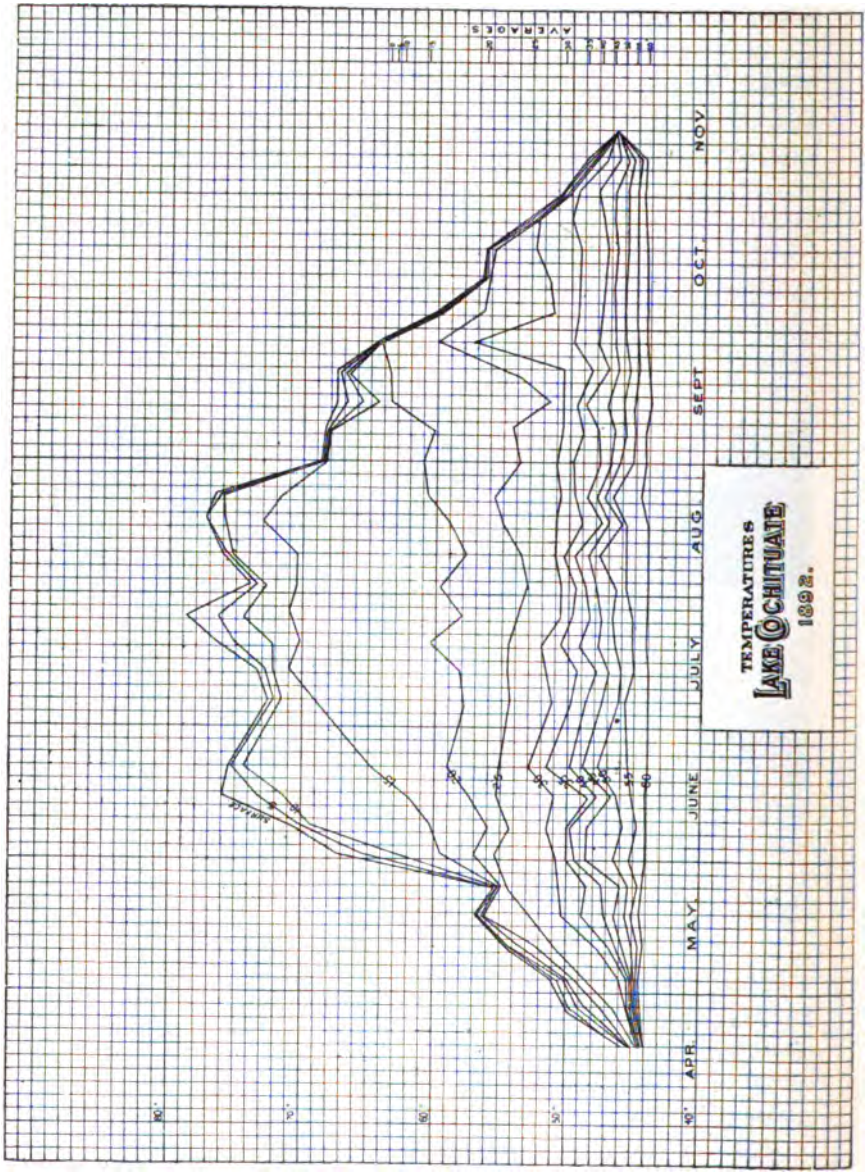
As supplementary to his investigation concerning the amount of dissolved oxygen in the water of ponds and reservoirs at different depths during the summer months, Dr. Drown made similar determinations during severe winter weather,

VIEW OF WELL-BASIN, IN THE FOREGROUND, AND CANAL BASIN, IN THE BACKGROUND, AT ABSECON PUMPING STATION, ATLANTIC CITY, N. J.

when the waters in question were covered with thick coatings of ice. The winter results fully confirmed those of summer, and showed that with exclusion of air the dissolved oxygen diminished in proportion to the quantity of organic material present.*

As a result of the " turning over " in the spring and autumn the waters of lakes and deep reservoirs become fouled to a

* Rep. Mass. Board of Health, 1892, p. 331.


TEMPERATURES
LAKE COCHITUATE
1892.
APR.
MAY
JUNE
JULY
AUG.
SEPT
OCT.
NOV.
AVERAGES

greater or less degree throughout their entire masses by virtue of the mingling of the waters of all layers during these periods of vertical circulation.

The deeply stained water of the bottom imparts a shade of its color to the body of the water at large, and the nitrogenous matter in solution, oxidizing to "nitrates," furnishes food for countless millions of "diatoms," and other growths whose development and decay cause many of the unpleasant tastes and odors with which our city supplies are so frequently afflicted.

Tastes and odors occur in waters of streams and rivers as well as in those of lakes, but the instances are fewer and the intensity is not so great.

The Boston Water-supply Department has made extended study of the *coloring-matter* common to the stagnant layer, and of the observed facts that the color at first deepens on exposure to air and afterwards bleaches out. The department finds that these phenomena are more strongly marked in proportion as the bottom-water is rich in salts of iron and manganese.

Those familiar with the properties and behavior of ferrous and ferric salts would have predicted that the soluble and light-colored ferrous compounds would, upon exposure to the atmospheric oxygen, oxidize to darker ferric salts, and ultimately fall as insoluble hydrated oxide and carbonate, leaving the water bleached; and it may be added that the slow fall of this depositing iron aids in ridding the water of other foreign materials, very much in the manner that the "coagulants" assist the purification process in mechanical filtration.

Sundry vegetable and peaty extracts are exceedingly difficult to decolorize, and waters containing them cannot be rendered colorless by storage in presence of light and air in a period short of many months. An improvement in color always results from open storage, but its entire removal is often impossible.

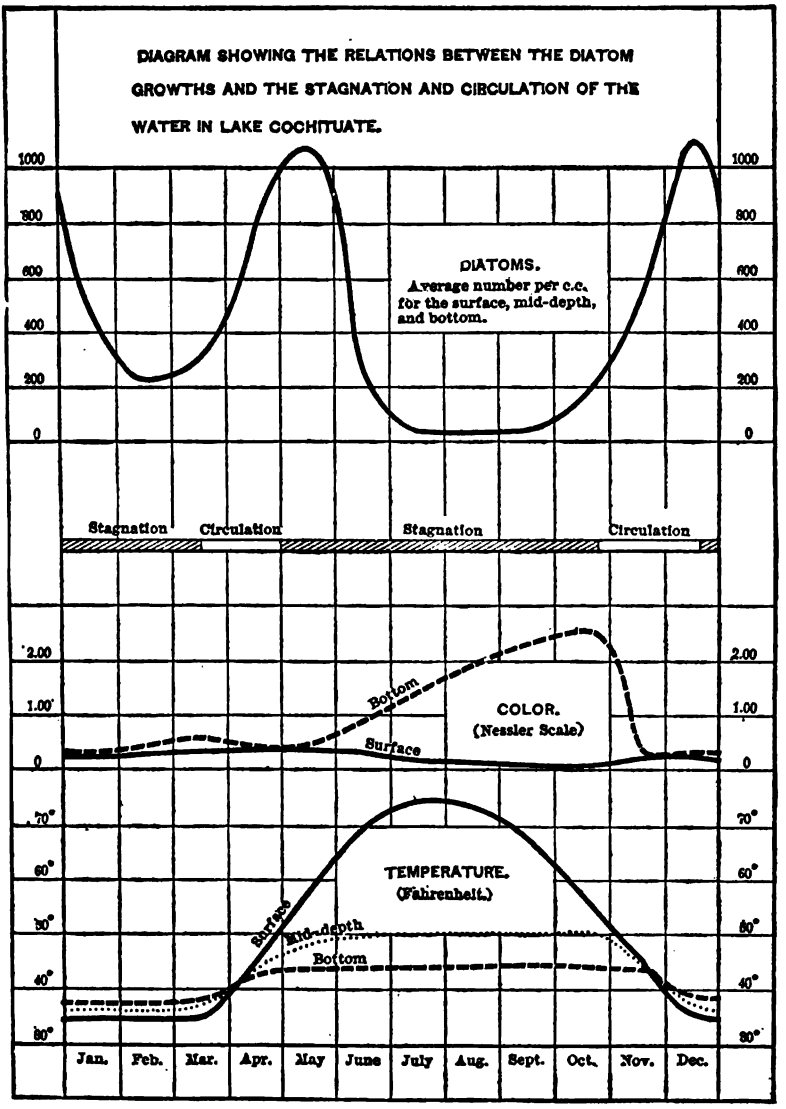
FitzGerald reports the following seasonal changes in color

of the waters of the Sudbury: The highest color is attained in the month of June, and then it rapidly lessens until September. Towards the end of October the color increases again until December, and then decreases until it reaches its yearly minimum in the middle of March. He offers the following explanation: In the early spring the swamps are overflowed and the color is low on account of dilution. Concentration causes increase in color until early summer, after which time the swamp pools cease to overflow, and consequently the brooks grow clearer. Autumn rains again fill the deeply colored swamp pools to overflowing and wash highly stained water into the streams, increasing their color, which is afterwards lessened in winter by the freezing up of the swamp sources.*

Subsequently FitzGerald experimented regarding the action of lights of different colors on the reduction of the brown color of water. The water under experiment was exposed during one month of summer in bottles of colored glass.

	Original Color.	Final Color.	Per Cent Reduction in Color.
In white bottle	1.05	0.39	
" "	0.85	0.19	
Mean	0.95	0.29	69.48
In blue bottle	1.02	0.39	
" "	0.85	0.24	
Mean	0.93	0.31	66.66
In yellow bottle	1.02	0.58	
" "	0.85	0.46	
Mean	0.93	0.52	44.09
In red bottle	1.02	0.54	
" "	0.85	0.47	
Mean	0.93	0.50	46.24

* " Met o. Water-supply," Rep. Mass. Board of Health, 1895, Appendix 3.



(After Whipple).

To return to what has been said concerning the growth of diatoms, the chart on the page opposite, prepared by Prof. G. C. Whipple,* makes the relation of such growth to the periods of vertical circulation very distinct.

Among other conclusions he found that diatoms flourish best in ponds having muddy bottoms; that their growth is directly connected with the phenomenon of stagnation; that their development does not occur when the lower strata of water are quiescent, but rather during those periods when the water is in circulation from top to bottom; that the two most important conditions for their growth are a sufficient supply of nitrates and a free circulation of air; and that both these conditions are found during the periods of vertical circulation.

Light also stimulates their growth. Hence it was to have been expected that a darkly stained water, which does not easily admit light, would prove a less favorable medium for the propagation of diatoms than a water of colorless character.

As has been said, air is essential to the abundant growth of these minute organisms, but the introduction of such air by means productive of violent agitation of the water would seem to be quite fatal to their development; probably through direct damage to the fragile cells of the plants.

Whipple observed the bad effect upon the growth produced by blowing a current of air through the water.† As a deduction from this we note a benefit to be derived from reservoir fountains and other means of agitation.

It has also been shown ‡ that many organisms of fragile structure are broken up by the pressure and currents of the mains, and that others die therein from lack of light and food. The oil they contain (see page 14) is thus liberated by disintegration, and as a result the water of the

* "Observations on the Growth of Diatoms in Surface-waters."
† J. N. E. Water-works Asso., xi. 3.
‡ *Ibid.*, xii. 7.

mains, as drawn at the taps, may smell worse than that of the reservoir.

It must be noted that the same organism may produce two very different odors, one during its period of development and quite another one at the time of its decay. For instance, an abundant growth of *anabæna* causes a distinct smell of "green corn" while the plants are yet alive, which changes to a pronounced "pig-pen" odor during the process of their decomposition. This change is quite characteristic.

While speaking of *anabæna* let it be added that the author observed a very interesting growth of this organism in the reservoir of a Western city.

The plant was distributed throughout the upper level from the surface to a depth of ten feet, producing disagreeable taste and smell in that part of the water, but leaving the deeper portions unaffected and entirely fit for use. Because of a sudden change of temperature, the water of the reservoir "turned over" in a single night, thereby distributing the organism and admitting highly objectionable water to the mains. Widespread public complaint was, of course, the immediate result.

This instance but adds weight to the demand for such form of gate-house in all city reservoirs as will permit of tapping off the water at any desired level; and it also shows, not only the necessity for biological and temperature observations, but that the entire storage need not be cut off from use because of the lack of fitness of a portion of the supply.

One of the most instructive cases of reservoir contamination by aquatic growth occurred at Brooklyn, N. Y., in 1896, and is reported by Leeds and Whipple in Engineering News, July 1, 1897. The cause of the difficulty was an abundant development of *asterionella*.

Judging from analysis of the bodies of asterionella, Whipple and Jackson found that in order to support a growth of such diatoms the water should contain the following, in parts per million:

N as NO_3.....	.079	K_2O.....	.043
SiO_2.....	1.780	Mn_2O_3.....	.030
Fe_2O_3.....	.083	SO_3.....	.014
CaO.....	.052	Total solids...	3.600
MgO.....	.045		

They considered the silica, iron, and manganese as those items most likely to be lacking in quantity sufficient to support an abundant growth of the plant.*

As is well known, the city of Brooklyn uses a mixed water, part of it being derived from wells driven into the sandy soil of Long Island and the balance of it coming from surface sources, such as Jamaica pond. The surface-water supplied the asterionella seed, the ground-water the necessary food, and the open Ridgewood reservoir, where the mixed waters were stored, allowed the light and heat of the summer sun to encourage abundant growth. The remedy in this case lay in using a by-pass direct to the mains, until such time as the reservoir water had recovered its normal quality. Light is essential to such a growth and the use of a by-pass was cheaper than constructing a reservoir cover.

A similar outbreak occurred at Penzance, England, in 1904. As at Brooklyn it arose from mixing a surface water with that from a deep well.†

ORGANISMS AND THE NUMBER OF THEM PER C.C. REQUIRED TO PRODUCE ODOR OR TASTE

Reported by Whipple ‡

	Number required per c.c.	Character of Odor and Taste.
Synedra pulchella.....	5000	earthy—vegetable
Cyclotella.....	5000	aromatic—fishy
Melosira.....	over 3000	earthy—vegetable
Anabæna.....	1700 standard units	moldy grass, green corn
Scenedesmus.....	25000 standard units	vegetable—aromatic

* J. N. E. Water-works Asso., xiv. 19.

† La Technique Sanitaire, June, 1906.

‡ See also Engineering News, June, 7 1900.

As to asterionella Whipple finds, by experiment, the following relations between the aromatic, fishy odor of the water and numbers of the organism present per cubic centimetre:*

Odor.	Number per c.c.
None	0 to 1,000
Very faint	500 to 3,000
Faint	1,000 to 5,000
Distinct	3,000 to 15,000
Decided	10,000 and over

In a letter to the author Professor Whipple gave the table on page 322 showing numbers of organisms found in cases of observed odor.

He added: "As to stating the number necessary to cause a noticeable odor, I do not feel sure enough about the figures to quote any. It might be done approximately in a few cases, as with asterionella, but I am sure that we cannot do more than guess at most of them."

As to what could be done to rid a water of the odors due to algal and other growths, the outlook was not very hopeful previous to the appearance of the "copper sulphate process" proposed by Moore and Kellernan in 1904 (Bulletins 64 and 76, U. S. Bureau of Plant Industry).

The method of applying this chemical is simple enough, and its use is very efficacious. Bought in bulk, it can be had at about five cents per pound, and its distribution is readily secured by filling it into perforated buckets, or even bags, and towing the same by row-boat or launch over the reservoir surface.

Decided objection was raised against such a process of "disinfecting" a public water supply, and the opposition was expecially marked in England, but the use of it is still with us and is likely to stay, for the reason that the "dose" is minute

* J. N. E. Water-works Asso., xiv. 1.

NUMBERS OF ORGANISMS FOUND BY WHIPPLE IN INSTANCES OF OBSERVED ODOR

Organism.	Odor.	Date.	Locality.	Number of St. Units per c.c.
Asterionella	Aromatic, geranium, fishy	Dec., 1897	Mt. Prospect Res., Brooklyn	50,000
Cyclotella	Faint aromatic	April, 1899	Ridgewood Res., Brooklyn	25,000
Diatoma	" "	Oct., 1900	Mt. Prospect Res., Brooklyn	13,000
Meridion	Aromatic	May, 1894	Pond at Chestnut Hill, Mass.	5,000
Tabellaria	"	May, 1890	Lake Cochituate	2,500
Melosira	Vegetable	Oct., 1900	Hempstead, L. I.	8,000
Synedra	"	Sept., 1897	Ridgewood Res., Brooklyn	20,000
Volvox	Fishy	.....	Rochester, N. Y.	.....
Eudorina	Faintly fishy	Aug., 1900	Mt. Prospect Res., Brooklyn	900
Pandorina	"	Aug., 1895	Pond at Chestnut Hill, Mass.	5,000
Dictyosphærium	"	Aug., 1897	Mt. Prospect Res., Brooklyn	1,000
Anabæna	Grassy and moldy, green corn, etc.	Aug., 1899	Long Pond, N. J.	9,000
Rivularia	Grassy and moldy			3,000
Aphanizomenon	Grassy	Oct., 1896	Laurel Lake, Fitzwilliam, H. N.	3,000
Uroglena	Fishy and oily	April, 1892	Norwood, Mass.	17,000
Synura	Cucumber	Oct., 1891	Glen Lewis Pond, Lynn, Mass.	7,000
Dinobryon	Fishy and rockweed	July, 1890	Scott Res., Fitchburg, Mass.	4,500
Bursaria	Fishy, Irish moss			
Peridinium	Fishy, clam-shells	July, 1891	Mystic Lake, Somerville	7,500
Glenodinium	Fishy	Aug., 1893	" "	10,000
Chlamydomonas	Fishy and moldy	Nov., 1898	Spot Pond, Malden, Mass.	700
Cryptomonas	Aromatic	Jan., 1900	Creek, Lodi, N. J.	10,000
Mallomonas	Aromatic, fishy	Sept., 1896	Lake Cochituate	3,500

and is only occasionally required, that it is reliable in results, and that experiment has shown that it is not followed by the evil consequences predicted.

It must be remembered that it is not added to the water continually, but is used only at stated and widely separated intervals,—namely, at those times when the " crop " of minute organisms become so well grown as to produce objectionable effect upon the water.

Even though all of the chemical employed reached the public water-mains, which is far from being the case, yet the actual quantity of metallic copper so represented would bear favorable comparison with the amount of the element present in many of our common articles of food; for instance:

QUANTITY OF COPPER, CALCULATED AS THE METAL, IN VARIOUS FOODS. STATED AS MILLIGRAMS PER KILOGRAM *

Almonds	36.8
Apricots	1.0
Cherries	2.3
Cocoa	47.0
Cucumbers	45.0
Egg, yolk	5.6
Egg, white	7.2
Figs	15.1
Grapes	1.0
Kidney (beef)	4.0
Milk (cow)	1.6
Oatmeal	4.2
Peas (French)	59.4
Potatoes	2.8
Strawberries	8.0

The Tomhannock reservoir at Troy, N. Y., is occasionally " coppered " with a dose of 1 part of blue vitriol (copper sulphate) to 3,500,000 parts of water, by weight. This would corre-

* J. Ind. and Engr., Chem., 7: 498.

spond to .073 milligram of metallic copper per kilogram of water.

According to Kemna it must be admitted that the salts of copper are poisonous in certain doses, but it is equally true that their toxicity has been greatly exaggerated, and the proscription of traces of the metal in foods has been one of the errors of hygiene.

The human organism easily tolerates copper and the small quantities employed to destroy algæ are absolutely harmless.*

Perhaps one reason why the "coppering" of reservoirs has led to so much criticism is because of the dead fish that are to be seen after the chemical has been applied. When considering this effect upon fish life, one should bear in mind that the "dose" has of necessity to be applied uniformly over the surface of the water, and each acre of such surface presumably receives the same amount, irrespective of the depth of water that the acre covers. As a result, the shallow parts of the lake receive temporarily a greater quantity of the sulphate, per cubic foot of water, than do those which are deeper; again, the entire quantity of chemical intended for the whole body of the lake is delivered to a few inches of its surface layer; therefore, until diffusion has taken place, fish which chance to swim into such water receive a very concentrated dose and are likely to be affected by it. Distribution is complete by the time the water reaches the public mains, and, moreover, the minute dose used has been more or less completely disposed of through its action upon the organisms for whose destruction it has been employed.

By a judicious watching of the shallow bays of a reservoir, from which seeding of the whole main body of water may at times occur, and by applying the sulphate of copper to these bays locally, the need for the chemical throughout the reservoir may often be avoided. For such work the use of a syringe such as is employed in a green-house for the spraying of plants is very convenient.

* La Tech. San., Aug. 1906, p. 172.

In a paper before the Section on Hygiene of the Eighth International Congress of Applied Chemistry, 1912, Kellernan presented the following table:

QUANTITY OF COPPER SULPHATE REQUIRED TO KILL VARIOUS FORMS OF ODOR-PRODUCING ORGANISMS

	Copper Suplhate Required, Expressed as Parts, per Million Parts of Water		
Anabæna	.09	Kirchneriella	5. to 10.
Asterionella	.1	Leptomitus	.4
Beggiatoa	5.	Microspora	.4
Chara	.2 to 5.	Navicula	.07
Cladophora	1.	Oscillatoria	.1 to .4
Cladothrix	.2	Peridinium	2.
Clathrocystis	.1	Scenesdesmus	5. to 10.
Cœlosphærium	.3	Spirogyra	.05 to .3
Conferva	.4 to 2.	Ulothrix	.2
Euglena	1.	Uroglena	.05
Fragilaria	.25	Volvox	.25
Hydrodictyon	.1	Zygnema	.7

He adds a list of twelve genera of algæ that in his experience are causing trouble in reservoirs and ponds:

NUMBER OF OBSERVED CASES

Anabæna	27	Conferva	56
Asterionella	9	Crenothrix	13
Beggiatoa	20	Fragilaria	19
Chara	26	Navicula	21
Cladophora	17	Oscillatoria	49
Clathrocystis	23	Spirogyra	43

Jackson claims that blue-green algæ will die if the water be "coppered" one part to five million. His dose for Mellosira or Synedra is one to two million, and he claims that the former gives no odor of growth, but only that of decay. He finds that coppering runs out certain forms of organisms and substitutes others by a sort of selective action, but those thus substituted are not likely to be odor-producers; and he further notes that, while "bottom" or decomposition odors are easily shaken out by aeration, "top" odors, viz., those of growth, have to be removed by filtering out the organism, or killing them by copper sulphate, or both. In this opinion, filtra-

tion of either type is effective for removal of odors of growth, but he believes that aeration would be worse than useless for living plankton, for the reason that the agitation would tend to mechanically release the oil causing the taste, which oil is not very easily oxidized.

Naturally the cost of treatment with sulphate of copper will depend in part upon the amount of the chemical that is to be used, which in turn is determined by the kind of organism that it is intended to kill; but it may be said that a mixed growth of Mellosira and Asterionella was removed from the Troy reservoir at an expenditure of 14.9 cents per million parts of water treated, labor included. The dose was one part of copper sulphate to 3,500,000 parts of water by weight.

In the article by Kellernan above quoted there are figures given indicating the safe limit for treating water with copper sulphate when certain fish are to be protected.

COPPER SULPHATE, EXPRESSED AS PARTS, PER MILLION PARTS OF WATER

Black bass	2.1	Pickerel	.4
Carp	.3	Suckers	.3
Catfish	.4	Sunfish	1.2
Goldfish	.5	Trout	.14
Perch	.75		

It must be noted that these figures assume a thorough mixing of the sulphate solution with the whole body of water. They would not hold for the unequal distribution and resulting local concentrations already mentioned.

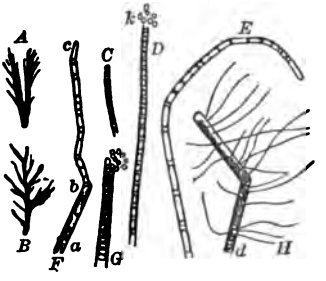
Although copper sulphate is toxic to typhoid bacilli and has been proposed for water disinfection, yet the dose required is larger than that for the destruction of algæ and its employment has not been uniformly satisfactory, in that it does not kill the pathogenic organisms with certainty. Moreover, for protection against typhoid the administration of the dose would have to be continuous. For such work of disinfection better results can be secured by the use of bleaching-powder or liquid

chlorine. Simple storage of water for some hours in copper vessels will kill *B. typhosus*. In this connection it is interesting to note the following from *Water*, Aug. 15, 1905:

"In the 'Ousruta Sanghita'—a collection of medical lore in Sanskrit, probable date 2000 B.C., chap. xlv., verse 15—appears this instruction: 'It is good to keep water in copper vessels, to expose it to sunlight, and filter through charcoal.'

"In the 'Neghrund Bhusan'—a collection of medical maxims from the 'Ayura Veda,' the earliest Sanskrit work on medicine extant, of about the same date—in the chapter on water, in the last *sloka* but two, it is directed to treat foul water by boiling and exposing to sunlight and by dipping seven times into it a piece of hot copper, then to filter and cool in an earthen vessel. It appears from the above that the principles of disinfection and filtration were understood by the ancient inhabitants of India."

In some reservoirs which have been formed by the extensive flooding of swamp bottoms there may develop objectionable growths of *Crenothrix*, a general term denoting a group of aquatic plants which at times give much trouble because of a tendency to develop in the street mains and clog the pipes. The growth is often discovered quite unexpectedly, being dislodged by the current attending hydrant flushing or by the draft caused by fire-engines. Dead ends are spots likely to harbor it, and its long rusty filaments have been mistaken for horse manure.



CRENOTHRIX.

There are three types of the growth, each possessing the peculiarity of precipitating from the water in which it grows its own particular metallic hydroxide. By far the commonest of the three is *Crenothrix Kuhniana*, which demands iron for its development and which deposits large amounts of iron hydroxide as the result of its growth.

Crenothrix ochracea precipitates aluminum hydroxide and is yellow to yellowish white in appearance. Its usual color is that of ochre, as it nearly always precipitates some iron with the aluminum. The third species, *Crenothrix manganifera*, precipitates manganese hydroxide, and is dark brown or black in appearance.

The growth of all three species is encouraged by a lack of oxygen, with a consequent reducing action in the soil or water.

WATER PIPE NEARLY BLOCKED BY GROWTH OF CRENOTHRIX.

Each of the three species seems to use a selective power in precipitating the special oxide ascribed to it, and about one-third of its dry weight is composed of the oxide selected, whether it be of iron, manganese or aluminum.*

The iron required for growth must be in solution, and the quantity demanded would seem to be about 0.3 part of Fe per million.

In order that the iron may be in solution, we naturally would expect the dissolved oxygen to be low and the quantity of reducing agents, such as organic materials, to be high, and those are the conditions that we find in practice to be favorable to the development of the plant.

It is likely to be encountered in waters from swampy, peaty

* See full paper by D. D. Jackson, J. Soc., Chem. Ind., 1902: 681.

sources, where dissolved oxygen is scanty and where the necessary iron in solution may be had. Driven wells in such localities frequently furnish it. Darkness favors its growth, and its development in city water-mains is often excessive, resulting in a material reduction of the carrying capacity of the pipes. The writer has some doubt about the " manganese " variety of crenothrix being as rare as some think it is, he having found large quantities of manganese in a heavy Wisconsin growth. Beythien and others have, moreover, noted that the presence of manganese in water directly favors the growth of the ordinary form of *crenothrix.*

Beyond the mechanical stopping of street pipes, crenothrix is exceedingly objectionable to the laundry interests of the community, for the reason that its rusty filaments cause " iron stains " to appear upon white linen.

Removal of the iron by oxidation and filtration is the best guard against troubles due to *crenothrix.*

The stripping of reservoir sites and the removal, so far as possible, of all the vegetable material of the upper soil, has been advocated and carried into practice with a view to diminish the amount of plant food and thereby avoid the troubles arising from the excessive growth of the taste- and odor-producing organisms.

Decomposition of recently killed vegetation takes place under water quite rapidly at first, but the process is shortly converted into one of exceeding slowness, particularly where the covering water is deep. So permanent, in fact, is timber which has been deeply submerged that the oaken piles which in prehistoric times supported the buildings of the Swiss " lake-dwellers " are still firm and solid, although black in color. On the other hand, alternate flooding and exposure to sun and air is quickly destructive of vegetable matter, and as a result a reservoir with very gentle sloping sides furnishes conditions less favorable to a high-grade water-supply, particularly if there be considerable variation in the water-level. Even though the high-water mark be always maintained, sloping sides per-

mit thin layers of water to be heated by the summer sun, thus encouraging abundant growth of aquatic plants, if there be sufficient food present for their nourishment. These plants subsequently decay to the damage of the water.

It is especially undesirable to have the bottom of a storage-reservoir remain exposed for more than one season, for the reason that vegetation may develop in such quantity as to injure the water when the bare slopes are again submerged.

The Boston authorities removed the soil from the site of the Wachusett reservoir (6.46 square miles or 4135 acres in area)

LAKE VYRNWY (LIVERPOOL WATER SUPPLY).

at a cost of $2,536,000. Some 800 holes were dug to determine the average depth of the top-soil layer, and it was concluded to take away 9 inches from the wooded portions and 11½ inches from the cleared lands.*

Such stripping cost about thirty-six cents per cubic yard but this did not include tree and bush removal.

As a provisional standard, 1½ to 2 per cent of organic matter, as determined by the loss of ignition of a sample of earth dried at 100° C. (212° F.) was fixed upon as the permissible limit of organic matter that might be allowed to remain on the bottom and sides of the reservoir.

No stripping of the soil from the bottom of the Vyrnwy

* Rep. Mass. Board of Health, 1895.

reservoir, supplying Liverpool, nor from the Ashokan reservoir lately completed for New York, was done.

At Columbus, O., the reservoir built to store the water of the Scioto river has an area of about 255 acres.

"It was not deemed necessary to remove any of the surface soil except to a very limited extent around former human habitations within the submerged area; but responsive to the requirements of the Ohio State Board of Health, all vegetable growths were cut down even with the ground, being then gathered into heaps and burned, while the stumps and roots of all trees and shrubs one inch or more in diameter were grubbed to a depth of one foot below the surface and similarly gathered and burned.

DETAILED COST OF CLEANING AND GRUBBING RESERVOIR SITE, COLUMBUS, OHIO

Item.	Days.	Rate.	Total.	Per Cent. of Cost.
Superintendent	255	$4.16⅔	$1,063	2.6
Time keepers	255	1.75	446	1.1
Foremen	1,030	2.50	3,325	8.2
Foremen	205	2.00	410	1.0
Carpenter	54	2.00	108	.3
Dynamite men	435	1.75	761	1.9
Laborers	14,491	1.50	21,737	53.3
Single horse	222	1.50	333	.8
Two-horse team	847	3.50	2,964	7.3
Dynamite	68,000 lbs.	.11½	7,820	19.1
Machinery and repairs	.....	.....	1,800	4.1
Total	.....	.....	40,767	100
Cost per acre, $159.50.				

A portion of the bottom land of about 36 acres had been cultivated but the remainder was thickly covered with a growth of trees and shrubs common to the forests or groves of the locality, some of them being five feet in diameter. The bottom lands were very fertile, and everywhere, in addition to the trees supported rank weeds, growing to a height of eight to thirteen feet." *

* See paper by Julian Griggs, read before the annual convention of the American Society of Municipal Improvements, Birmingham, Ala., October, 1906.

The stripping of reservoir sites and the removal of a portion of the upper soil entails very great expense when the surface to be stripped is at all extensive, as in the instance of the Wachusett reservoir supplying Boston.

In their report upon the probable cost of stripping the surface soil from the Ashokan reservoir site, Messrs. Hazen and Fuller stated it would possibly reach the great figure of $5,000,000.

In view of the expense of such treatment for large reservoirs, the question is pertinent, " Does it pay? "

At Holyoke, Mass., the annual water report for 1908 says: " Great care had been taken in cleaning and stripping the reservoir by removing all vegetable and organic matter, thus lessening to a minimum the food supply for supporting living organisms in the water. The thorough cleaning of the reservoir has not been wholly successful, as an aquatic plant known as ' Chara ' has grown and flourished in the reservoir all summer and imparted to the water a taste and odor that made it unfit for drinking or even for cooking purposes."

Mr. J. M. Diven * has had interesting and contrasting experiences with both stripped and unstripped reservoirs:

" The Elmira reservoir was as thoroughly stripped as possible; great care was taken to keep out the first washing from the drainage area and the muddy flood waters. There was little or no marsh land on the drainage area, the catchment area being seemingly ideal. The reservoir was clean and clear; on the sides the slopes were abrupt, and there was very little shallow water.

" At Charleston, S. C., the drainage area was largely swamp, and there was much decayed vegetable matter on all of the area drained, the water being decidedly peaty. The reservoir covered a large surface, was shallow, and absolutely unstripped or even cleared. Much of the land flooded was composed of black muck or decayed vegetable matter.

" In the first case (Elmira) the conditions were at the first satisfactory and the water good for several years. But trouble

* American Water-works Asso., 1908.

from algal growth came in time and has steadily grown worse, in spite of strenuous efforts to remedy the condition.

"The second case (Charleston) was troublesome and unsatisfactory from the first, but has somewhat improved and promises to continue to improve."

On the other hand, Wachusett reservoir, above referred to, has given satisfaction from the first. The shores are clean and the water clear and attractive. No odors have developed and the color of the entering water has fallen from 45 to 18 through the bleaching action of open storage. All *B. coli* are removed by the passage through the reservoir. One evidence of the beneficial result of stripping in this instance is the fact that the bottom water, 102 feet down, is as good or slightly better than that of the surface; at least such was its appearance at the time of the writer's visit. Inasmuch as this reservoir is the best illustration that we have of "stripping" on a large scale, it will be well to add here the analytical results of the reservoir water and of those of the entering streams.*

CHEMICAL ANALYSES—WACHUSETT RESERVOIR

July 7, 1914

(PARTS PER MILLION)

	Quinnepoxet Inlet.	Stillwater Inlet.	Surface near Dam.	Bottom near Dam.
Turbidity	V. slight	Slight	V. slight	V. slight
Sediment	Slight	Considerable	V. slight	V. slight
Color	45.	34.	18.	20.
Odor, cold	F. veg.	F. veg.	None	V. F. veg.
Odor, hot	Dis. veg.	Dis. veg.	V. F. veg.	F. veg.
Residue on Evaporation:				
Total	43.5	53.5	32.5	38.5
Loss on Ignition	14.5	16.0	9.5	10.0
Fixed	29.0	37.5	23.0	28.5
Free ammonia	0.024	0.032	0.022	0.046
Albuminoid Ammonia:				
Total	0.284	0.264	0.170	0.130
Solution	0.204	0.176	0.126	0.126
Suspension	0.080	0.088	0.044	0.004
Nitrates	none	none	0.010	0.020
Nitrites	0.001	0.001	none	none
Oxygen consumed	5.9	4.8	2.4	2.4
Hardness	5.	14.	10.	8.
Iron	2.2	0.37	0.03	0.01

* Analysis by State Board of Health.

More recently R. H. Stearns * reports the color reduction of water in the Wachusett reservoir, to be 66 per cent following a storage period of 615 days. The data show the color of the influent water to be 43.5 parts per million and that of the effluent 14.7 parts per million.

While the latter figure is readily secured it is not so easy to obtain a true value for the former, because of the many different waters that may flow into a large reservoir; nevertheless there is manifestly a decided bleaching effect to be credited to the action of the prolonged storage.

Such a result of stripping as is illustrated by the Wachusett reservoir is not to be expected always. The Boston Metropolitan water supply is caught in a granite region and the streams furnish waters which, though colored, are not turbid. The water flowing into Wachusett reservoir is low in plant food and, therefore, as all such food was stripped from the reservoir bottom during construction, there is nothing to maintain heavy algal growth. Should a reservoir of similar size be constructed elsewhere, say in the Middle West, or wherever turbid stream flow is common, then so good a return for the money expended in the stripping could not be secured and the stripping would not pay. This is but another instance of how desirable it is to judge of each case upon its own merits.

The writer advocates the expenditure of comparatively little money in the preparation of sites for large storage-reservoirs, except under the conditions above noted, for the reason that, although thorough stripping will likely give immunity from algal growths for some years, yet freedom from the occurrence of taste and odor in the stored water may not last for long. Sooner or later there will probably be carried into even the most carefully cleaned reservoir enough food material to sustain a plankton growth of a density governed by the local conditions.

The character of the tributaries must be considered as well as the nature of the bottom of a proposed reservoir, for it is

* J. N. E. Water-works Asso., March, 1916.

manifestly loss of money to improve the latter if the former can quickly replace much of what has been taken away.

For the sake of general appearances, if for no other reason, trees, shrubs and bushes should be removed. Dead, standing timber and fallen logs are most unsightly and are very likely to produce complaint from the visiting public. In other words, the reservoir site should be cleared and grubbed, with, of course, entire removal of every vestage of human habitation; but beyond that it usually does not pay to go. The portion of the flooded land lying between high-water and low-water marks should receive especial attention, for the reason that during the periods of its exposure it is capable, if uncared for, of presenting an unpleasant appearance and provoking adverse criticism; with the further objection that heavy weed growth may develop if it be long uncovered, which growth will contribute toward the production of taste and smell when the water again covers it.

Broadly speaking, an "old bottom" is better than a new one, because it is likely to contain less plant food; but the rule has many exceptions.

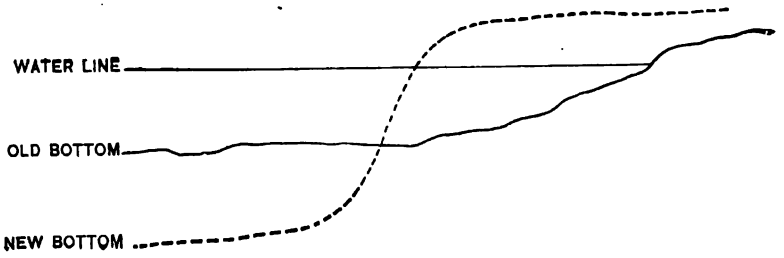
Even natural lakes are frequently seen "in bloom,"—that is, loaded with minute life,—and they so remain for a period during which their waters are not acceptable for domestic use.

Aeration, filtration, and the judicious, occasional use of copper sulphate constitute the processes at our disposal for combating the annoyance arising from algal growths, and their use will ordinarily give greater satisfaction than the expensive stripping of reservoir bottoms.

Successful removal of very considerable odor due to growth of algæ has been secured by the use of double sand filtration and double aeration at South Norwalk, Conn. A detailed description of the plant is given in J. N. E. Water-works Asso., for March, 1916 by H. W. Clark, through whose advice the work was undertaken. The good results obtained are similar to those following double filtration at Springfield, Mass., by a plant whose operation is described as removing "the organ-

isms and the tastes and odors and causing a very substantial reduction of the iron, organi cmatter and color of the water treated."

Depth of reservoirs is not so important as the presence of food-supply in the matter of the existence or absence of organisms. The Massachusetts Board of Health reports the case of Pilling's Pond, a very old storage-reservoir, eighty-five acres in surface, with an average depth of only three feet. No abnormal growths appeared in this reservoir, not did the water become offensive although its temperature at times reached 80° F. The explanation offered is that, owing to the age of the reservoir, the bottom mud no longer contains food-supply.* The deepening of shallow flowage near shore can be best accomplished by the method recommended by FitzGerald and sketched herewith.



It is particularly desirable that no depressions should be permitted to remain upon a reservoir bottom, which could be cut off from the receding water as the basin becomes drawn down, and thereby form stagnant pools. Such spots would surely prove breeding-places for algal growth. Free drainage should be provided for all pockets of this kind, or, better still, they should be filled up. It may be said here that the work of stripping a reservoir bottom is sometimes complicated by the occurrence of deposits of soft material rich in organic products and too deep to be economically removed. It is good practice to fill in the surface of such places with good

* Rep. Mass. Board of Health, 1890 [1], p. 749.

sand or gravel, after having taken away the more superficial portion.

Such filling need be but a few inches thick in order to protect the water from damaging contact with the bed of muck below, providing no upward movement of ground-water, as from a spring, is taking place, in which case even a much thicker layer of gravel would be of no avail.

Sulphuretted hydrogen may add its disagreeable smell to the odors occurring in new reservoirs, particularly shallow ones. The decomposition of vegetable material, killed by flooding, causes a reduction of the sulphates present to sulphides, and these sulphides are further acted upon by the acids also formed by such decomposition, with liberation of the foul-smelling gas. The author found this gas on one occasion due to a somewhat unusual cause. The reservoir-dam had been built of blast furnace cinder, and the water was, in consequence, strongly impregnated from the sulphur compounds contained therein.

Waters from underground sources should be distributed for use as soon as possible after they have been brought to the surface; for, as we have seen, they are commonly well supplied with plant-food in solution, and, under the influence of sunlight, there is danger of abundant development of objectionable algæ if much time for open storage be allowed.

With surface-waters the case is quite the reverse, and long storage becomes a distinct advantage.

Sedimentation of suspended matter, and destruction of bacteria by simple lapse of time, are two sources of benefit arising from the impounding of surface-water.

Bacteria often die but slowly, and although a large percentage of their number will perish through storage, it should not be forgotten that they are very small and very light, and consequently are very long in settling, expecially in clear water; so that it should not be expected that a reservoir could do the efficient work accomplished by a filter.

Sedimentation of small particles is slower in winter than in summer, owing to the increased viscosity of the colder water.

The water for Cincinnati was taken from the Ohio River and delivered to the consumers with but a few hours' subsidence in the Eden Park reservoir, while the water of Covington was carried for an average of thirty-two days in the subsiding-reservoirs before it was delivered to the people.

From these results the average reduction of bacteria in the Ohio River water by thirty-two days' subsidence is shown to have amounted to nearly 94 per cent.

The following table, showing the influence of sedimentation as measured by the number of bacteria per cubic centimetre of water, is taken from the report of the Cincinnati Engineer Commission:

Bacteria, per c.c. of Water.		Reduction of Bacteria by Sedimentation.
Cincinnati (Raw).	Covington (Settled).	
1472	272	88.32
1599	194	87.87
5062	172	96.60
——	182	96.41
1656	53	96.80
2042	56	97.26
1561	63	95.96
1526	75	95.09
684	20	97.08
329	26	92.10
1232	112	90.91
1144	84	92.66
1436	102	92.90

Cincinnati has now a new filter plant; but the above figures, applying to past conditions, still illustrate as fully as ever the value of sedimentation.

Percy Frankland found the following numbers of bacteria per cubic centimetre in Thames water at the intake of the Grand Junction Company, and in water from the large reservoir of the company, where the greater part of it

had been stored for six months, and none for less than one month:

Intake	1991	bacteria
Reservoir	368	"

The West Middlesex Company causes its water to pass through two storage-reservoirs before it is delivered upon the filter-beds. The influence of such passage is seen in the following counts of bacteria as made by Frankland:

Intake at Hampton	1437	per cubic centimetre
After passing first reservoir	318	" "
After passing second reservoir	177	" "

The value of sedimentation was shown at Philadelphia during the prevalence of typhoid fever in that city in 1891. "By much the highest mortality is in the twenty-ninth and thirty-second wards. This is an elevated section of the city, newly improved and occupied for the most part by well-to-do people. The drainage is good and the laws of health are doubtless as well observed as in any other portion of the city. But these wards are too high to draw water from the subsiding-reservoir, and they are accordingly furnished by direct pumpage from the river. This is the case also in the twenty-eighth ward adjoining, and the district so supplied extends southward including the fifteenth ward, another well-to-do part of the city where typhoid is especially prevalent. These four wards, furnished by direct pumpage, have a population of 184,000, and report 317 cases of typhoid fever, or at the rate of 172 to 100,000 inhabitants." *

The favorable influence of precipitating mud in hastening the fall of bacteria was demonstrated in this laboratory some years since. The result was to have been expected in view of the well-known tendency of falling solids to drag down other matters with them. Similar results were observed by Kruger.†

* See also "Bacterial Reduction by Storage," *Engineering Record*, Aug. 13. 1898; "Influence of Dredging Lake Bottom, Public Water-supply," Hill, p. 96,

† Zeit. f. Hygiene, VII. 86.

Dr. A. C. Houston, of the London Metropolitan Water Board, has undertaken some very extended researches upon the question of water purification as a result of storage. He found that in stored Thames water the death of typhoid bacteria took place rapidly, although the rate varied with the temperature of the water. In cold water they lived longer than in warm, and 50° F. seemed to be a critical point above which their mortality rate was much increased.

In his 7th Research Report, Houston states that typhoid bacilli lived in stored raw Thames water for the following lengths of time: At 32° F., five weeks; at 41° F., four weeks; at 50° F., three weeks; at 64° F., two weeks.

Even these figures do not tell the entire story. Put in more detail they read:

	At start.	1 week.	2 weeks.	3 weeks.	4 weeks.	5 weeks.
32° F.	103,328	47,766	980	65	34	3
41° F.	103,328	14,894	26	6	3	—
50° F.	103,328	69	14	3	—	—
64° F.	103,328	39	3	—	—	—

He concludes: "It is difficult to escape the belief that thirty days' storage of river-water is tantamount to sterilization, so far as the microbes associated with water-borne epidemic disease are concerned."

When experimenting with an artificially infected water to determine the effect of storage upon the typhoid bacillus, Dr. Houston felt that any error so introduced was upon the side of safety, because he had previously shown the "cultivated" typhoid organism to have a greater longevity than the "natural" *Bacillus typhosus*. In his report he dwells at length upon the advantages to be derived from "adequately storing the *raw* impure river waters." Even if there were no economic reason for storing a river-water before rather than after filtration, yet it would be well to follow that course, aside from any question

of agal growths, for the reason that sedimenting silt greatly assists in bacterial removal.

Dr. Houston further says: "I am well satisfied that a well-stored, rapidly filtered water is likely to be safer than an unstored, slowly filtered water."

It is possible to go even further than this, for one can see how dangerous it might be to deliver, directly to the consumers, the water of a small and apparently pure mountain stream. The dejecta of a single typhoid patient would render so small a volume of water highly infectious, if no storage intervened, and an outbreak of the disease might follow.

Although Dr. Houston is doubtless sound in his judgment that a great measure of safety will result from four weeks' reservoir storage of a polluted water, yet we must be assured that the period of storage is real and not simply apparent; or, in other words, we must know that *all* of the water really does remain in the reservoir for the specified length of time before it is used for public consumption.

Where the inlet and outlet of a reservoir are near together, as is not uncommonly the case, it makes but little difference what the capacity of the total storage may be; the water simply slips in and out again with practically as little stay as though the reservoir were a stand-pipe.

If the lake be long, narrow, and deep, and all of its water be obliged to traverse its entire length before being taken for supply, then the conditions would appear ideal for purification of the inflowing water before the outlet was reached, and yet even under those excellent conditions it is possible to have introduced unexpected and upsetting factors, as is instanced by the history of the typhoid epidemic at Auburn, N. Y.

Lake Owasco is one of the so-called "finger lakes" of western New York. Its length is about ten miles, breadth one mile; its watershed is about 190 square miles; and its depth is about 175 feet. A small stream enters its head, and Auburn, a city of some 30,000 inhabitants, has an intake located at the north end or foot of the lake and forty feet below the surface.

The temperature of the water at that point in May, 1913, I found to be 42° F.

The peculiar feature of the case which has special interest here is the possibility of polluting material of fecal character being transported from a village near the head of the lake, down the inlet stream, and then northward for the entire ten miles of the lake's length to the Auburn intake situated near the lake outlet.

We have all faithfully held to the dictum that "sedimentation and time" are the great purifying agencies upon which to rely for the natural improvement of a once polluted water; and it takes a good deal of evidence to persuade us that sewage of a small village could make the trip down such a lake in a length of time and in such a manner as to dangerously affect the water of the lower end. Experimental data, however, have been secured showing that such a result can actually take place. Investigation showed the following facts: The village sewage was, of course, small in volume, but during the winter months it was deposited at several points upon the banks of the inlet stream and there it collected in a more or less frozen condition until the occurrence of the spring thaw, at which time there was opportunity for much accumulated fecal material to be washed into the lake in a state of suspension. There was also a chance of its being actually ferried upon cakes of ice, for the reason that certain privies were located upon bridges and fecal matter was dropped upon the very centre of the ice-covered stream.

As stated, the shape of the lake is long and narrow and its axis lies north and south. It must be further noted that the prevailing wind is from the south, with a tendency to blow the surface-water directly toward the city intake at the north end.

By means of triangulation and the use of floats constructed so as to be moved by water currents existing at the different depths of from five to twenty feet, it was ascertained that the upper stratum of water moved northward with the wind, as would have been expected. The rate of this movement being

ascertained, it was found that with relatively light winds the movement of the water down to a depth of five feet amounted to about 3 per cent of the wind movement, while at lower depths this water movement diminished to as low as three-quarters of one per cent of the wind movement. Thus, to quote from the figures of Mr. Ackerman, who made these tests, with a wind movement of six miles per hour the percentage which the water movement was of the wind movement was as follows: At 5 feet depth, 3.2 per cent; at 10 feet depth, 1.74 per cent; at 15 feet depth, 0.87 per cent; at 20 feet depth, 0.75 per cent.

With a higher wind velocity the water also travelled with greater velocity, but its movement was then not so large a percentage of the wind movement. Thus, with a wind blowing 17 miles an hour the water movement at a depth of five feet amounted to but 1¼ per cent of that of the wind. From these data it was easy to calculate that pollution entering the head of the lake could make the trip to the foot of the lake in three days or less.

Knowing, as we do, from Dr. Houston's experiments, that cold water below 50° F. will favor the longevity of the typhoid fever bacillus, it is easy to see how entirely possible it would be for living germs to reach the intake in dangerous condition.

It will be noted how striking is the resemblance which some features of this case bear to the classic instance of the outbreak of typhoid fever at Plymouth, Pa., where the whole trouble came from dejecta of a single individual being thrown out upon a hillside where it froze and accumulated for weeks and finally, upon the coming of the thaw of spring, was washed into a stream tributary to the city reservoir. This sudden washing of accumulated fecal material furnished in both of these instances a volume of pollution out of all proportion to the amount which would be daily derived from the contributing population during ordinary times of fair weather, and as a result it overtaxed and broke down nature's ordinary means of purification and protection.

There is no question but that this particular case, showing, as it does, the dangers that may arise from such winter accumulation, and showing further the possibility, under favorable conditions, of the transportation of such material over considerable distances in a lake, will cause many of us to materially amend our notions about the dependence to be placed upon lake and reservoir storage as a means of protection against the evils following water pollution. We should not trust to simple storage without a thorough knowledge of just how it is being accomplished. The writer has in mind an instance of a large lake some five miles in length which has a stream entering within one mile of a city intake, and, because of the entering water having a low specific gravity, there is a possibility of its flowing over the surface of the lake toward the intake whenever the wind is in the right direction. The great length of that lake is, under such circumstances, of small value for purification purposes. In another instance a cold stream entered the reservoir and its water hugged the bottom until the intake was reached, hence the low level gate drew unstored water.

All of this certainly goes to show that we should be cautious about banking too strongly upon the efficiency of reservoir purification under all circumstances, and it demonstrates the necessity of our being well acquainted with the conditions surrounding each individual case before venturing an opinion on the matter.

It should be noted here that, in judging of the bacterial efficiency of lake or reservoir storage, the interpretation of the results of an examination may be obscured by an increase in the total count of bacteria reported due to the disturbing influence of the spring or autumn " turnover."

Doubtless the most apparent advantage to be obtained from storage is the removal, by sedimentation, of those suspended materials, mostly of mineral character, which cause unsightly turbidity in water. Quiescence is naturally contributory to such removal while " scouring velocities " tend toward an opposite result.

SETTLING-TANKS SHOWING "SKIMMING" DISKS. DENVER, COLO.

SAME TANKS EMPTY OF WATER SHOWING DEPOSIT OF SEDIMENT.

Dappert gives the velocities required to move sundry materials as follows.*

	Ft. per Second.
Very fine clay	0.40
Very fine sand	0.70
Light vegetable soils	0.83
Sand as coarse as flax seed	0.91
Gravel, size of a pea	1.40
Small pebbles	2.52
Pebbles one inch in diameter	3.00
Pebbles size of hen's eggs	4.15

The theory of the clearing of water by settlement, and the most economic size for purely sedimentation-reservoirs, are questions which have been exhaustively discussed in our engineering societies by such men as J. A. Seddon, Whitney, and others, and reference must be had to their voluminous papers for full information.

But it may be here said that the bulk of sediment capable of falling within a reasonable length of time will be found to deposit within about twenty-four hours, the balance settling out with much slowness. It is therefore very questionable economy to provide for a sedimentation period of over thirty-six hours.

Percentage of suspended matter removed from water by twenty-four hours' plain subsidence.†

Kansas City, Missouri River	82 per cent
Cincinnati, Ohio	62 "
New Orleans, Mississippi	45 "

Whitney calls attention to the fact that "as the material in suspension grows finer the weight of each particle decreases so much more rapidly in proportion than its surface that there is, relatively, a larger amount of surface area in these fine particles, and a great deal of surface friction in their

* Engineering News, 55: 126.

† J. N. E. Water-works, Asso., xvii. 165.

THE CAPEDIMONTE RESERVOIRS, NAPLES, ITALY.

movement through a medium. Consequently they settle very slowly."

"Ordinary convection currents, induced by normal changes of temperature, would be sufficient to keep these fine particles in suspension, as it is known that currents of air keep fine particles of dust and ashes in suspension." *

One of the most peculiar forms of settling-chamber the author has seen was prepared for use by the Denver Union Water Company, at Denver, Colorado. It is readily understood by reference to the illustration on page 345. The tanks are each 20 by 20 by $3\frac{1}{2}$ feet, and water is admitted through nine rectangular orifices near the bottom. The effluent is "skimmed" from the surface by ninety 16-inch disks which connect with the underdrains by means of one-inch vertical iron pipes. The 15-inch partitions, shown on the bottom, are arranged to assist in the flushing out of the sediment. At the time of the writer's visit the efficiency of the settling-tanks was represented by a removal of a large part of the suspended matter and of 32 per cent of the bacteria present in the raw water.

We have already seen that exposure of subterranean waters to sunlight commonly results in development of objectionable vegetable growths. The somewhat peculiar reservoirs at Paris which hold the Vanne spring-water, supplying a large portion of the drinking-water used in the French capital furnished an illustration of dark storage. The springs are about 107 miles distant, and the grade of the conduit-pipes is 1 centimetre per 100 metres (0.4 inch per 328 feet). In order to secure sufficient storage, and yet to economize space within the walls of Paris, two reservoirs were built, one on top of the other.† The lower one is constructed of concrete, and 1800 concrete columns support the upper story, which is of brick This upper chamber is covered by a roof which rests on brick continuations of the concrete columns. The water area in

* Wiley's "Agric. Anal.," i. 180.

† The Montmartre reservoirs of Paris of three superimposed chambers instead of two.

each reservoir is 272 by 136 metres (892 by 446 feet), and its depth in the upper one is $8\frac{1}{4}$ feet and in the lower one $13\frac{3}{4}$ feet. The total storage capacity is 200,000 cubic metres (52,800,000 U. S. gallons). The temperature of the water is constantly 48.2° F. in winter and 51.8° F. in summer. No trouble has ever been experienced with algal growths or odors. Cleaning takes place but once in five years, at which time about half an inch of compact hard deposit is removed. The reservoirs hold a supply sufficient for about six days.

Another underground storage system which will repay a visit is that of Naples, Italy. Old quarries lying in the hill of Capedimonte overlooking the city have been enlarged and cemented with the result shown in the illustration on page 347. Five parallel tunnels have thus been formed some 150 feet below the surface of the ground. Their dimensions are 35.4 feet in height and 30.3 feet greatest width. The depth of water is 26 feet, and the galleries are separated by a space of rock left unexcavated. The capacity of the five basins is 21,120,000 U. S. gallons.

Underground storage of water is also to be found at Gibraltar, and is peculiar in the respect that military precautions are considered in its accomplishment. The writer having had special opportunities for examining this particular system of water-works, a short description of what he saw may not be out of place.

Gibraltar is, beyond all things else, a fortress. The visitor is continually reminded of this fact, not only by the visible signs of military occupation everywhere present, but also by the rules and regulations with which the place positively bristles. The assumption upon which the garrison appears to act is that a state of war continually obtains, and that a hostile attack should be momentarily expected.

So carefully are the military secrets of the rock guarded that even the officers of the post are individually not fully informed as to the nature of the defences outside of the sections where their duties lie. To such an extent is this carried that the engineer officer whose duty it was to design the works for

"NORTH FRONT," GIBRALTAR.

the new water-supply told the writer that he could not go up the west face of the rock until his pass had been signed in England.

It may be easily imagined that the foresight which goes so far as to cause the garrison to be fed on "siege-rations" one day in each week would not permit the possibility of such garrison being deprived of its water-supply through the operation of an enemy.

The area of "Gibraltar" is small, but that portion of it which is within the old walls and which constitutes the "city" is densely populated. Roughly speaking, the civil population may be placed at 20,000, while the garrison numbers 6000. These figures would be, of course, liable to modification in time of actual war.

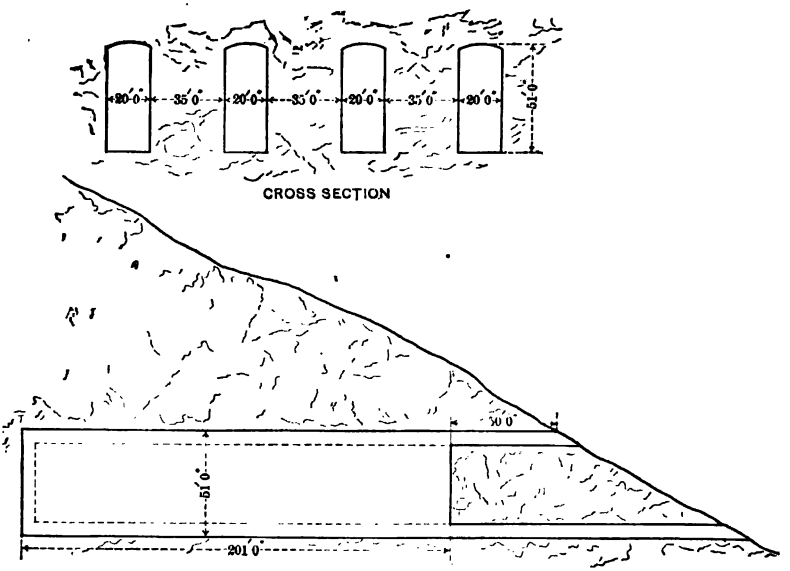
The bold-faced "Rock of Gibraltar," with the pictures of which we are all so familiar, rises sheer from the "Devil's Tower Road," on the "North Front," and faces the land side, not the sea as most people fancy. It looks toward Spain, and makes the approach of an enemy from that direction all the more difficult. The east side is also very precipitous; while the west slope, although decidedly steep, permits of enough fairly level ground being found at its base to furnish a foothold for the "city" with its circumvallating walls.

Gibraltar is not limited to a single source of water-supply. For ordinary uses, such as flushing, street-sprinkling, and the like, a brackish water is used which is derived from wells sunk in the flats north of the rock, and near the neutral grounds. The supply so secured is about 25 per cent sea-water in winter and about three times that amount in summer, owing to the variation in seasonal rainfall. It is pumped to a tank located in the "Moorish Castle," a portion of the ancient defences, and flows thence to the town by gravity. This water is metered and charged for at the rate of $\frac{1}{4}$ peseta for 100 Imperial gallons, or about 40 cents per 1000 U. S. gallons.

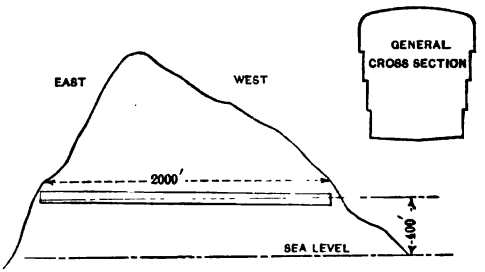
Situated not far from the "Alameda Gardens," on the west slope of the rock, is a distilling-plant for furnishing a potable supply from sea-water. The apparatus is well pro-

tected and ready for an emergency, but is not ordinarily in use.

The principal water-supply for Gibraltar is obtained from



SECTIONS OF STORAGE-TUNNEL RESERVOIRS AT GIBRALTAR.



SKETCH-SECTIONS OF NEW STORAGE-TUNNEL RESERVOIR AT GIBRALTAR.

the rain, and a careful inspection of the west face of the rock will show a whitish patch near the top which acts as the catchment area. This area contains about sixteen acres, and has been carefully cemented at a cost of $1\frac{1}{2}$ pesetas (about 30 cents) per square yard. The water falling thereupon, averaging $33\frac{1}{3}$

WEST FACE OF ROCK, GIBRALTAR (SHOWING CATCHMENT AREA IN UPPER LEFT CORNER).

inches annually, passes through a rough strainer of "polarite" and sand, and is thence delivered into the underground storage-reservoirs.

The catchment area above described has been recently much extended and embraces a portion of the east face of the rock.

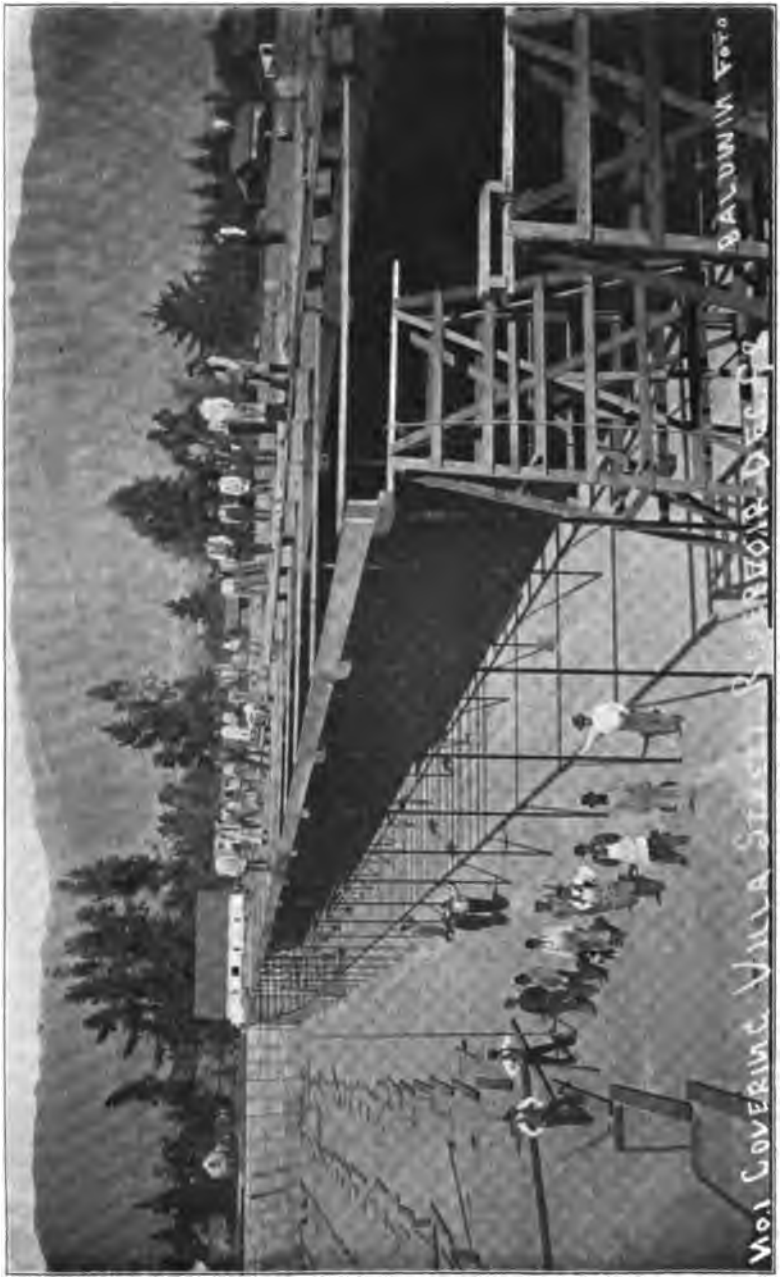
The original four storage-reservoirs are of the same size, and are of tunnel form, being 201 feet long, 22 feet wide at the top, and 18 feet wide at the bottom, with a height of 51 feet, see cross-section, page 352. The sides are stepped off by 4-inch ledges every 7 feet, measured vertically. The sides, bottoms, and ends are concreted and then plastered with four coats of a mixture of equal parts of cement and fine limestone. The filtered rain-water is admitted to each tunnel through an 18-inch cast-iron pipe, carried to the bottom of the chamber.

Security against the shell-fire of an enemy is not the only advantage of this form of water-storage, for it must be remembered that the absolute darkness which prevails under such conditions inhibits the growth of aquatic vegetation, and the temperature of the water is maintained constantly at a low degree, in this instance 50° F.

The exact location of these reservoirs is not permitted the outsider to know, although their general form and dimensions are as given above. The internal measurements are correct, as stated, but the true angle of slope of the exterior rock-face is intentionally withheld. It will be noticed that the exterior ends of the tunnels are not excavated. This is for the protection of the water-supply against the artillery-fire of a besieging force.

A newer and much larger storage system has been driven through the entire rock from side to side, excepting, of course, the unexcavated ends. Exact information covering this development it is, naturally, impossible to secure, but the rough sketch given and the quotation here following will sufficiently illustrate its general character.

"The annual rainfall during the last 114 years has fluctuated between 77 inches (1855–6) and 15 inches (1800–1), and



COVERED RESERVOIR, PASADENA, CAL.

during that time there have been twenty-three years with more than 40 inches of rainfall and twenty-two years with less than 25 inches. In order to provide water by pipes to the whole of the Fortress in the event of three successive years of minimum rainfall, it will be necessary to have a collecting area of 37 acres and storage reservoirs of 17,000,000 gallons capacity. A collecting area of 10 acres has been provided on the sand slopes above Catalan Bay. This area is capable of yielding 240,000 gallons per inch of rainfall, i.e., an increased yield during average rainfall of 8,000,000 Imperial gallons per annum. The sand has been covered with corrugated iron sheets laid on a creosoted timber framing. With ordinary care this covering will be as durable and efficient as the older areas, and much less absorbent. The water from the area is collected in a channel at the bottom of the slope and conveyed in a tunnel about 2030 feet long through the rock to the four reservoirs constructed four or five years ago. The channel, both at the foot of the area and through the tunnel, has been made of sufficient capacity to collect and convey the whole of the water that may fall when the entire collecting area of 37 acres has been laid." *

Light, inexpensive covers are often thrown over reservoirs of considerable size and the sun's rays thereby excluded, with the result that algal growths are prevented.

The general character of the cover that was constructed at Pasadena is easily determined from the illustration on page 355, and the cost was as follows:

259,966 square feet of lumber	$4856
9373 feet of 2-inch pipe for posts (including 551 caps and freight)	987
Hardware	203
Mill-work (labor making corbels)	27
Cement (around foot of poles)	6
Engineering	151
Labor (including superintendence)	1004
Total	$7234

The area covered was 166,000 square feet, at a cost of 4.36 cents per square foot, or $345 per 1,000,000 gallons of storage.

* Gibraltar Public Health Report, 1903.

It is important to note that in all such covers the boards should be laid north and south, so as to avoid too long exposure of the same water-surface to what sun rays may enter through the openings between the planks.

With reference to the question of danger from ice formation the method of procedure proposed at Quincy was to "pump continuously into the reservoir during ice-making weather until full, then stop the pumps and supply the city from the reservoir until it was necessary to resume pumping. By this plan of either raising the water or allowing it to fall the ice does not become attached to the posts sufficiently to do any damage."

A similar variation of water-level in a stand-pipe, during freezing weather might however work disaster. At a town in northern New York a heavy ring of ice was formed while the water-level was about half way up the stand-pipe. Upon filling the water to a high level this ring was deeply submerged. It subsequently became loosened from the sides, rose with great force and took off the cover of the stand-pipe. Cases have occurred where, after the formation of such an ice ring, the lowering of the water left it suspended in the air and its subsequent fall greatly damaged the stand-pipe sides.

Maintaining a practically uniform water-level during cold weather is the reasonable procedure.

Whatever the design of a settling-basin may be, means must be provided for easy removal of sediment.

The means to be selected to clean small reservoirs will suggest themselves to the designer who is familiar with the local conditions. Gentle inclination of the reservoir floor toward a central sump is a usual provision.

Before recent changes were made the Mississippi water used at St. Louis was improved by plain sedimentation in artificial basins. In all about twelve feet of mud was deposited therein per year, but as cleaning took place about every sixty days, except during freezing weather, only about two feet accumulation was permitted. The cleaning was accomplished by

horse scraper aided by a siphon flow from an adjoining basin, except in those harder sections of the deposit which required hand spading as well as stream-flow. Under the conditions of simple sedimentation the cost of cleaning at St. Louis amounted to from $\frac{3}{4}$ to $2\frac{1}{2}$ cents per cubic yard of mud, according to its stiffness. The time for settlement varied from twenty-four to thirty-six hours, the lower figure being more common. Half of the suspended matter settled in twelve hours and 66 per cent in from twenty-four to thirty-six hours. Not enough additional sediment was found to separate upon longer storage to make it pay to use the additional time. As stated in his St. Louis report (page 72) Hazen figured the cost of cleaning the settling basins at 15 cents per million gallons of water settled. This is based upon an estimate of fifteen cubic yards of wet mud being deposited per million gallons of water passing through the reservoir and a charge of one cent per cubic yard for its removal. This is a lower average figure of cost than that for 1900, for which year the cost was 1.49 cents per cubic yard.*

Chemical precipitation was later added to the improvement process for the St. Louis water, the reagents used being sulphate of iron and lime. The data are as follows: †

Average dose per gallon of water treated:

Sulphate of iron	2.13 grains
Lime	7.39 "

Cost of treatment per million gallons of water treated:

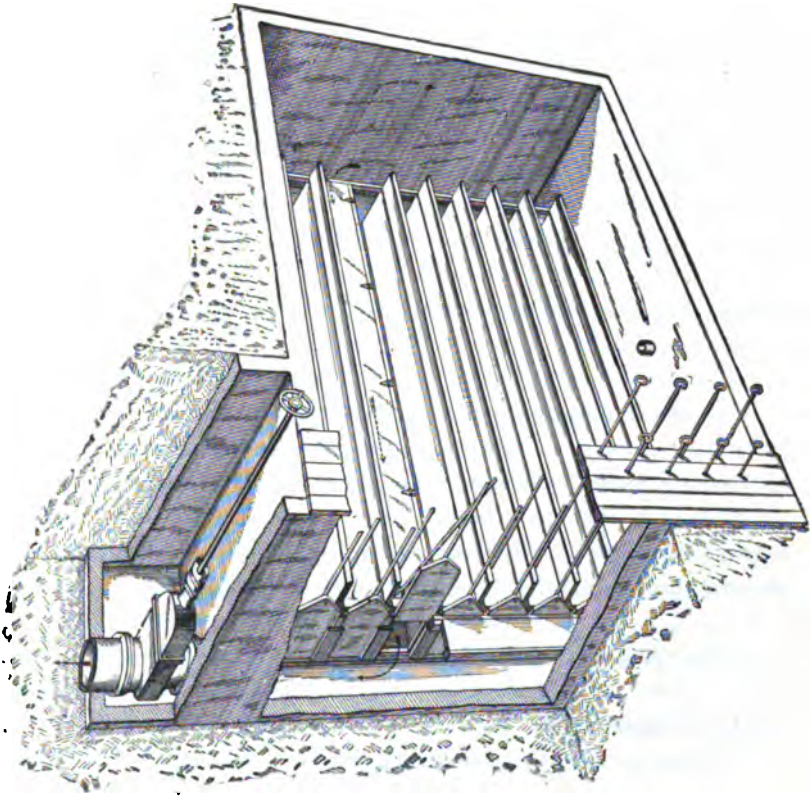
Sulphate of iron	$1.442
Lime	2.454
	3.896
Labor	0.579
Power	0.064
Improvements	0.021
Repairs	0.063
	$4.623

* J. N. E. Water-works Asso., 19: 226.

† Engineering Record, July 27, 1907.

The volume of water used for flushing in cleaning the basins being 2 per cent of the total water pumped.

One form adopted for quick cleaning is pictured on page 317. The illustration shows the method of removing deposit from



DEVICE FOR CLEANING A SETTLING-RESERVOIR WITHOUT THROWING IT OUT OF SERVICE.

reservoirs without throwing them out of use. It will be seen that a series of partitions, provided with hinged covers, is placed in the bottom of the reservoir. The compartments thus formed are open at one end and closed at the other by lift-gates, which lead into a common header. During sedimentation the covers are vertical and the silt falls to the reservoir bottom. Upon

closing down the shutters the deposit is trapped beneath them. If one or more of the gates be raised, the head of water forces the sediment out into the "header" and thence into the sewer. For larger reservoirs such a device is multiplied, and the shutters and gates are operated from paths of light construction.

However imperative it is to clean sedimentation tanks or reservoirs at suitable intervals, no such treatment can be profitably considered for those of a storage type. One might as properly attempt to clean the bottom of a natural lake. Sedimentation, of course, takes place in large reservoirs as well as in those of less size, but the volume of water flowing through them per square foot of bottom per year is but a fraction of what is stored for short intervals of time by those small basins, that are in comparison but enlargements of the city mains.

For the removal from a large reservoir of a considerable growth of grass the author saw barbed wire in successful use at Denver, Col. One end of the wire was fastened at a point on shore and the other hauled by a team of horses over quite a sweep of bottom. The weeds were cut off near the roots or else dragged out bodily and afterwards floated ashore.

"*Dew-ponds*" are unknown in this country but it may not be amiss to give the following description of them as they occur in England: *

"These ponds are familiar to those acquainted with the chalk downs. Many of them are of enormous antiquity, and are the handiwork of neolithic man. In some remote down districts, during long droughts, the extraordinary spectacle may be witnessed of villagers and farmers sending carts from the valley to the summit of the downs, in order to fetch water from dew-ponds for domestic and farm purposes. The reason that these dew-ponds do not dry up is that the radiation of heat from the earth at night is checked by a layer of non-conducting

* A. E. Carey, in "Water," Feb. 15, 1908.

medium. The surface of the pond is thus chilled to the dew point, and a deposition of the water vapor contained in the atmosphere takes place in the form of dew."

The care of watersheds has been already touched upon (page 300), but a further word is here in order.

Outside of the efforts of local authorities to safeguard the sources of public water-supplies, a number of State Boards of Health have taken up the matter and formulated rules for the protection of lakes and reservoirs. These rules are general in character and are fitted to specific cases by minor changes or additions to suit local circumstances. Those prepared for the Tomhannock reservoir supplying Troy, N. Y., read in part as follows:

1. No ordinary form of privy or cesspool shall be allowed within 150 feet of the reservoir or entering watercourse.

2. Privies maintained within above distance shall have absolutely water-tight vessels so as to allow of removal of dejecta to safe location for disposal.

3. Overflow of receptacles mentioned in (2) shall be prevented.

4. Dejecta from the vessels mentioned in (2) shall be disposed of by burying in trenches, or digging into soil, in such manner as to prevent surface wash, and at a distance not less than 300 feet from the reservoir or 200 feet from entering watercourse.

5. No sewage shall escape on ground-surface or into ground within 200 feet of the reservoir or of entering watercourse.

6. No garbage, kitchen waste, laundry waste, etc., shall be discharged upon or into the ground within 100 feet of the reservoir or 75 feet of entering watercourse.

7. No bathing shall be allowed in the reservoir or an entering watercourse and no animals nor poultry be allowed to stand, wade nor swim therein.

8. No stable, barnyard, hog-pen, hen-house, hitching-place nor manure pile shall be maintained within 150 feet of the reservoir or 75 feet of an entering watercourse.

9. Leachings from the items mentioned in (8) shall be deemed not properly purified unless they percolate through at least 150 feet of soil before reaching the reservoir or 75 feet before reaching an entering watercourse.

10. No manure shall be piled nor used within 150 feet of the reservoir or 75 feet of entering watercourse.

11. No fishing nor ice cutting shall be allowed on the reservoir.

12. No human burial shall be allowed within 200 feet of the reservoir or 50 feet of an entering watercourse.

Rules formulated to govern conditions on Lake Owasco within a distance of two miles from the intake of the city of Auburn, N. Y. are similar, namely:

	Least Permissible Distances from the Lake and Tributary Watercourses. Feet.
Privies, etc., of any kind that are water-tight	60
Privies, etc., for permanent storage or deposit without water-tight receptacles	150
Burying human excreta, etc	250
House slops, sewage, bath water	150
Garbage, waste, matter from creamery or cheese factory, etc	80
Stable, barnyard, hogpen, etc	60
Spreading compost containing human excreta	250
Spreading animal manure on land	75
Vegetable waste	75
Dead animals, offal, etc	100
Location of tents and other temporary shelters	150

When a lake is large enough to permit of navigation an additional rule applies, as in the instance of Skaneateles lake, furnishing the water-supply for Syracuse, N. Y.:

"No excreta, garbage, slops nor any decomposable or putrescible matter of any kind shall be thrown, discharged or allowed to escape or to pass into the lake from any steamer, barge, launch, sailboat or rowboat. Steamers, barges and other boats having water-closet or toilet accommodations shall be provided with removable water-tight receptacles, which shall be regularly emptied, cleaned and deodorized at least once each day."

These state rules are valuable so long as they remain elastic and retain their ability to fit local conditions by proper adjustment.

Every case must be judged upon its own merits; for the enactment of a too rigid general law will be likely to work harsh injustice on the one hand, or poor sanitary protection on the other.

A "reasonable" contamination, by riparian owners, of a water subsequently used for public supply is permitted by a decision of the New York Court of Appeals, although "Nuisances" are forbidden.*

It is entirely possible to protect a reservoir, and to a great degree the watershed also, if careful policing of the district be established. Country towns situated upon the banks of streams tributary to the reservoir are the sources of greatest danger, and an earnest effort should be made to remove all privies, manure heaps, farmyards, refuse dumps, and other sources of pollution from draining into the stream or any of its feeders. This is sometimes difficult to accomplish completely, but a high degree of thoroughness can be attained by suitable and tactful management.

Board of health rules are expected to cover the care of public watersheds, but rules and laws will not enforce themselves, and the city official is commonly at a distance and more interested in the distribution system than in that of collection. The most simple arrangement would seem to be to appoint a local physician in each town or village upon the watershed as the sanitary inspector for that particular district, and to give him authority to employ an intelligent laborer as a subinspector to do necessary work under his direction.

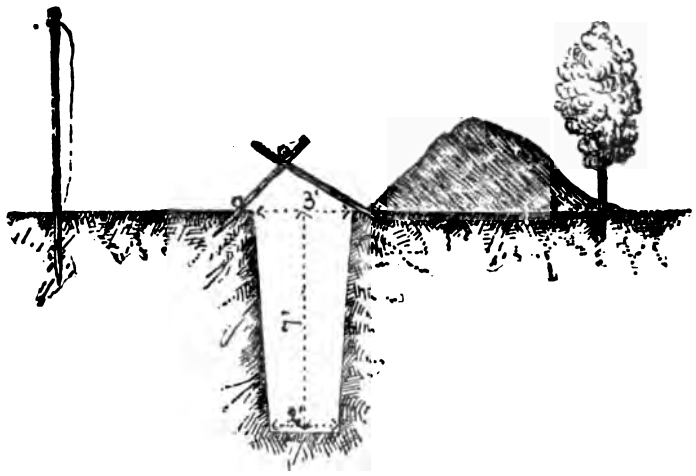
The writer had found this arrangement both efficient and cheap.

The physician-inspector would be in a position to know of cases of disease, such as typhoid, in his district and, being so informed, could take proper precaution against contamination of the public water, which act on his part would be of vastly

* Engineering Record, 64: 255.

more practical value than a location of the trouble by some sanitary commission after an epidemic was well under way.

The greatest responsibility borne by the inspector would be during periods when gangs of laborers were employed at construction work within the limits of the watershed. Should the workmen be many and the time of their remaining be two weeks or more, nothing short of incineration of all camp waste and night-soil should be demanded, and the utmost care should



(Courtesy of Wm. Wood & Co.)

CONSTRUCTION OF ARMY LATRINE PIT
Military Hygiene—Havard

be taken that sanitary instructions are carried out to the letter. A Woodruff pit, which can be constructed in a few hours, would be suitable for a temporary camp; while, if something more permanent were demanded, a well-constructed incinerating furnace should be built.

The proper sanitary managing of a camp is difficult enough when dealing with soldiers, where military discipline aids the officer; but when groups of ignorant, and usually foreign, laborers are to be housed and fed the road to success is distinctly harder.

Should the camp be large and likely to be occupied several

months, then it would be wisdom to surround it with a man-proof wire fence having but a single public gateway.

The indiscriminate use of the camp area for toilet purposes must be absolutely stopped, and to that end the area should be well cleared of all cover.

The reservoir to be protected and its tributaries must be guarded against use by the camp population at all hazard and this may require some additional wire fencing as well as watchful patrols.

Water for the camp should be delivered by pipe direct to the camp enclosure. This water should, if possible, be a gravity supply derived from a local source, but if it be necessary to use the reservoir or an entering stream, then enough water should be pumped to the camp to supply bathing facilities as well as for other uses, so as to diminish the chance of the men bathing in the source of supply.

Reference has already been made to the advantage of destroying all human dejecta by fire, but, if such disposal should be impossible then the latrines should be located on as level ground as possible, to reduce the risk of their contents being scoured out by local wash. For the same reason the entire camp should be placed on level ground, if that arrangement can be made. Latrine pits, if used, should not be too deep and their contents should be daily sprinkled with lime and fresh earth and regularly protected from the reach of flies. No latrine pit should be allowed to fill with dejecta, but when the contents reach within a foot of the ground-surface the pit should be filled with earth and a new one dug.

For the use of men while on the work away from camp a portable latrine with very shallow pit should be used and it should be moved frequently. Care about this point is very important, for the writer found that on one occasion the very trench in which they were laying the water-main had been used by the laborers for toilet purposes.

In order to secure early information of danger threatening the catchment-area the Water Commissioners of one New England city " have adopted the plan of offering a reward to

any one who reports a case of typhoid or other intestinal disease occurring on the watershed." At Barnesville, O., provision was made for the appointment of a local inspector, who must inspect the drainage area every two weeks and note any violation of the rules. Any case of sickness found by the inspector must be reported to the local board of public affairs, "which board shall be responsible for the care of the patient with respect to his causing any pollution of the water of the reservoir." *

One large city goes even further: The writer is advised that the local physician in each town on the watershed is encouraged to report typhoid fever by receiving from the Water Department a cash payment for each case reported. Such payment is sufficient to cover the probable amount of his fees should he have had charge of the case. The patient is then removed beyond the limits of the watershed and cared for at the expense of the water department. The plan works well and avoids the danger of cases being concealed.

Besides caring for the sources of pollution noted above, the sub-inspector's duty should include the patrol of any railroad track which may run near the reservoir or entering stream. This question of danger from *railroad pollution* has but recently been recognized. Although the possibility of its occurrence is always well worthy of consideration, there is no question but that it greatly varies in importance with change in topography, soil, or season. Rocky, steep slopes are easily washed by the rain, and frozen embankments naturally fall into the same classification, while flat road-beds and sandy soils offer better chances for polluting material to be disposed of by natural methods.

Whatever the character of the road-bed, it should be the sub-inspector's care to remove all night-soil dropped from passing trains within the zone of danger, and he should exercise greater vigilance in winter than during summer.

* Ohio Sanitary Bulletin, July, 1904.

Not every one of the people traveling by rail is in good health, and an appreciable number of them may be properly assumed to be in a condition to excrete typhoid bacilli in their dejecta. Should such material be dropped from the train at the moment when it was passing over some critical portion of a city's water system the result might be distinctly serious.

It is not profitable to pay too high a price for safety, and the railroad danger is small, except under unusual circumstances; but certain precautions are warranted because reasonable both in method and cost.

To the writer it seems that the remedy should be applied to the road-bed rather than to the train. Locking closet doors while passing points of danger is but a poor makeshift and fails under pressure of necessity in the very cases whence most trouble is likely to arise. As to the conversion of the car toilets into dry-earth closets, or equipping them with closed storage tanks, it is highly probable that the public would not approve of any such arrangement.

It should not take unusual skill and labor to design the side-ditches of the railroad at dangerous points so as to catch what drops from the train, and cause such of it as may not be removed by the sanitary patrol to percolate through the embankment. At points of special danger, as where the line crosses streams near the intake, the roadway should be carried upon tight-decked structures, and polluting material dropped thereon should be carried away by suitable drains. Even disinfection could be employed in cases of special risk.

Pollution danger from railroad construction is naturally greater than that caused by operation, and being of the same type as that already considered under labor camps it should be cared for in the same manner.

Highway pollution is commonly not serious, whether carried by wind or wash. It, of course, increases the total count of bacteria, but there is small danger of its containing any human excrement.

Hospital drainage has seldom threatened a watershed, but

the character of such an institution would instantly suggest that special care should be exercised in looking after the disposal of the sewage.

The International Joint Commission, appointed to investigate the pollution of the Great Lakes and boundary waters, submitted a list of questions to six sanitary engineers, three representing the United States and three for Canada. The result of their work here follows:

1. Speaking generally, water supplies taken from streams and lakes which receive the drainage of agricultural and grazing lands, rural communities, and unsewered towns are unsafe for use without purification, but are safe for use if purified.

2. Water supplies taken from streams and lakes into which the sewage of cities and towns is directly discharged are safe for use after purification, provided that the load upon the purifying mechanism is not too great and that a sufficient factor of safety is maintained, and, further, provided that the plant is properly operated.

3. As, in general, the boundary waters in their natural state are relatively clear and contain but little organic matter, the best index of pollution now available for the purpose of ascertaining whether a water-purification plant is overloaded is the number of *B. coli* per 100 c.c. of water expressed as an annual average and determined from a considerable number of confirmatory tests regularly made throughout the year.

4. While present information does not permit a definite limit of safe loading of a water-purification plant to be established, it is our judgment that this limit is exceeded if the annual average number of *B. coli* in the water delivered to the plant is higher than about 500 per 100 c.c., or is in 0.1 c.c. samples of the water *B. coli* is found 50 per cent of the time. With such a limit the number of *B. coli* would be less than the figure given during a part of the year and would be exceeded during some periods.

5. In waterways where some pollution is inevitable and where the ratio of the volume of water to the volume of sewage is so large that no local nuisance can result, it is our judgment that the method of sewage disposal by dilution represents a natural resource and that the utilization of this resource is justifiable for economic reasons, provided that an unreasonable burden or responsibility is not placed upon any water-purification plant and that no menace to the public health is occasioned thereby.

6. While realizing that in certain cases the discharge of crude sewage into the boundary waters may be without danger, it is our judgment that effective sanitary administration requires the adoption of the general policy that no untreated sewage from cities or towns shall be discharged into the boundary waters.

7. The nature of the sewage treatment required should vary according to the local conditions, each community being permitted to take advantage of its situation with respect to local conditions and its remoteness from other communities, with the intent that the cost of sewage treatment may be kept reasonably low.

8. In general, the simplest allowable method of sewage treatment, such as would be suitable for small communities remote from other communities, should be the removal of the larger suspended solids by screening through a $\frac{1}{4}$-inch mesh or by sedimentation.

9. In general no more elaborate method of sewage treatment should be required than the removal of the suspended solids by fine screening or by sedimentation, or both, followed by chemical disinfection or sterilization of the clarified sewage. Except in the case of some of the smaller streams on the boundary, it is our judgment that such oxidizing processes as intermittent sand filtration and treatment by sprinkling, filters, contact-beds, and the like, are unnecessary, inasmuch as ample dilution in the lakes and large streams will provide sufficient oxygen for the ultimate destruction of the organic matter.

10. Disinfection or sterilization of the sewage of a community should be required wherever there is danger of the boundary waters being so polluted that the load on any water-purification plant becomes greater than the limit above mentioned.

11. It is our opinion that, in general, protection of public water supplies is more economically secured by water purification at the intake than by sewage purification at the sewer outlet, but that under some conditions both water purification and sewage treatment may be necessary.

12. The bacteriological tests which have been made in large numbers under the direction of the International Joint Commission indicate that in some places the pollution of the boundary waters is such as to be a general menace to the public health should the water be used without purification as sources of public water supply, or should they be used for drinking purposes by persons traveling in boats.

13. It is our judgment that the drinking water used on vessels traversing boundary waters should not be taken indiscriminately from the waters traversed, unless subjected to adequate purification, but should be obtained preferably from safe sources of supply at the terminals.

14. While recognizing that the direct discharge of fecal matter from boats into the boundary waters may often be without danger, yet in the interest of effective sanitary administration it is our judgment that the indiscriminate discharge of unsterilized fecal matter from vessels into boundary waters should not be permitted.*

As growing out of a consideration of reservoir-water, it is interesting to note the influence of the channels of distribution, i.e., conduits and city mains, upon the character of the supply. The differences between the following sets of samples, taken by the author at a city intake and drawn from taps at the other end of the town, show the changes in the water result-

* Engineering News, July 23, 1914.

ing from its passing through the pumping system and street-mains:

	Bacteria per Cubic Centimetre.	
	Intake.	Tap.
January 12	4,022	1502
February 5	3,322	436
April 10	17,665	2425
October 30	1,487	1090

It is instructive, and suggestive of the beneficial action of mains, to note that, for the year ending September 30, 1892, when the lake-water was pumped directly into the Chicago mains from the old short tunnel intakes, the percentages, by wards, of deaths from typhoid to total deaths were:

Wards less than two miles from the lake.....6.0 per cent
Wards more than two miles from the lake.....5.7 "

At the time of testing the new filter for the city of Lawrence, Mass., the efficiency was found to be a removal of 98.3 per cent of all bacteria; but by the time the water reached the city hall 99.1 per cent had disappeared. This credit should be given the street-mains for the destruction of 0.8 per cent of the total germs.

Similar evidence is presented by chemical analysis of water from the same town: *

	Albuminoid Ammonia.	Nitrogen as Nitrates.
Water as pumped to reservoir	.174	.135
Water from reservoir	.144	.146
Water from city tap two miles from reservoir	.117	.192

In examining the Freiburg supply Tils found that the water from the reservoir contained fewer bacteria than that from the mountain source. But he also found that the bacteria increased in numbers after passing through the service-mains. Percy Frankland also found that the deep-well water furnished by the

* Rep. Mass. Board of Health, 1890.

Kent Company contained fewer bacteria as it issued from the wells than when delivered by the city mains to the consumers. This is at variance with the usual experience in this country, but an increase in number of ordinary bacteria during flow in street-mains is by no means unknown here; thus Dunwoodie uniformly finds such increase to take place in the mains of Erie, Pa.

When securing ground for a proposed reservoir the purchase of all desirable building sites adjacent thereto should be carefully considered, for the reason that their price is likely to be advanced later because of the added attraction due to the lake formed.

CHAPTER VIII

GROUND-WATER

THE circulation of water in the soil is governed by gravity and surface-tension, and the latter is in turn affected by the structure of the soil, its composition, and the per cent by volume of the empty spaces between its particles.

The " voids " in the subsoils of South Carolina and Maryland, as determined by Whitney, show as a mean for twenty-three localities 48.73 per cent by volume, the extremes being 37.29 and 65.12.

The rate at which water will flow through a soil * is dependent not only upon the pressure gradient and the aggregate volume of the voids, but also, and more particularly, upon their separate dimensions; for it can be readily seen that the inhibiting influence of friction will rapidly increase with the fineness of the soil-grain.

This is observed in the following table, extracted from " Physical Properties of Soils." † The rates of flow through a certain depth are calculated for a uniform water-content of 12 per cent.

Soil (Maryland).	Number of Grains per Gramme of Subsoil.	Voids, Per Cent.	Relative Time, Minutes.
Pine-barrens	1,692,008,503	40	8
Truck	3,342,323,489	45	16
Tobacco	8,258,269,975	50	33
Wheat	10,357,871,515	55	45
River terrace	11,684,097,513	55	49
Triassic	14,735,778,341	55	56
Helderberg	19,638,258,585	65	100

* In this connection see Wiley's " Agric. Anal.," i. 159.

† Bulletin 4, U. S. Depart. of Agric.

E. L. Rogers * reported that American and French estimates showed the average velocity of water in sands to be about one mile a year, or about an eighth of an inch a minute.

Slichter † gives an extended table of velocities under sundry conditions, from which these few instances are extracted: (the gradient is 100 feet to a mile, temperature 50° F., and the porosity 32 per cent):

Diameter of Soil Grain. (Millimeters.)	Velocity Miles per Year.	Diameter of Soil Grain. (Millimeters.)	Velocity Miles per Year.
0.01	0.00026	0.80	1.63300
0.10	0.02551	0.90	2.06600
0.20	0.10210	1.00	2.55100
0.30	0.22960	2.00	10.21000
0.40	0.40810	3.00	22.96000
0.50	0.63770	4.00	40.81000
0.60	0.91830	5.00	63.77000
0.70	1.25000		

Professor Slichter has devised an electrical method of determining the rate of flow of ground-water which gives more rapid results than the chemical ones commonly employed.‡ He describes it as follows: (see illustration page 375).

The up-stream well is charged with a strong electrolyte, which dissolves and passes down-stream with the moving water.

The passage of the electrolyte toward the lower well is shown by the gradual movement of the needle of the ammeter, and the final arrival at the well is shown by a sudden and strong deflection of the needle. In an hour or two a very good indication of the rate can be obtained by noting the slope of the current curve already obtained.

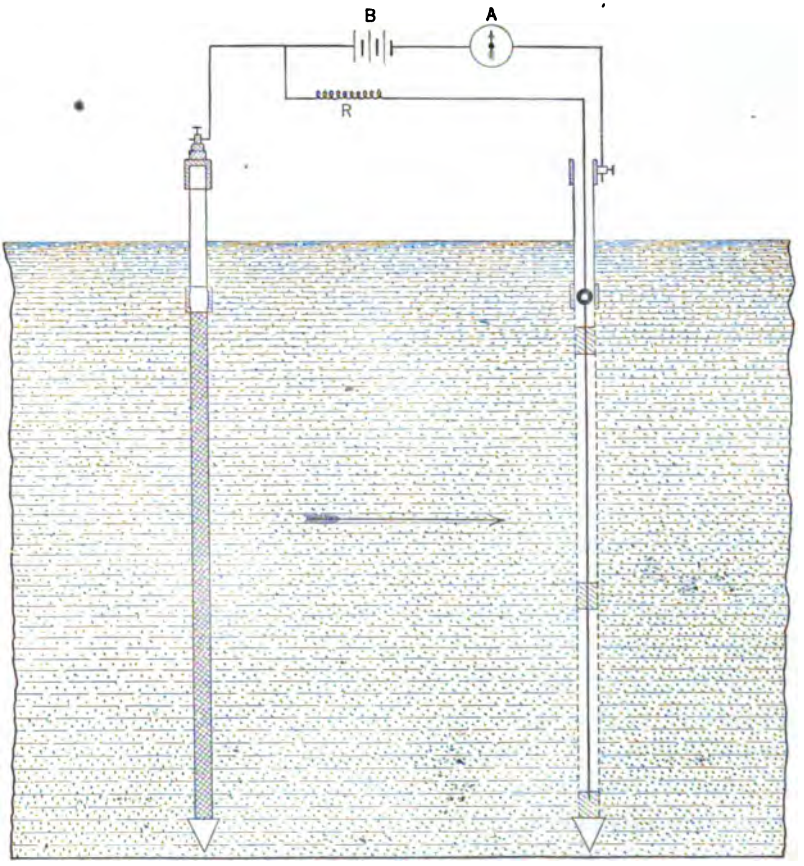
Of the numerous electrolytes tried up to the present time, ammonium chloride has given much the best results. With this salt a current of sufficient intensity to throw the needle of a recording ammeter can be obtained by the use of a few dry cells.

* Engineering Record, 25: 4351.

† Water Supply Paper No. 67 U. S. Geol. Sur.

‡ *Ibid.*

The electric circuit to the wells can be made in various ways. A brass rod, insulated from the well tube, and lowered into the down-stream well by means of a rubber-covered wire,



ARRANGEMENT OF APPARATUS FOR DETERMINING THE VELOCITY OF GROUND-WATER BY SLICHTER'S ELECTRICAL METHOD.

(A = ammeter; B = battery; R = resistance. The arrow shows direction of supposed motion of the ground-water.)

may serve as one electrode, the casing of the same well constituting the other electrode. In this case the indication of the movement of the ground-water will not be noted until the electrolyte has reached the lower well, where its presence will be

shown by a sharp rise in the current curve. Instead of this, the two wells themselves may be used as the electrodes, in which case the gradual passage of the electrolyte down-stream can be observed from the beginning but the final indication of its arrival at the lower well is less pronounced. The best method is a combination of these two. The wire from the casing of the lower well is run to one pole of the battery with the ammeter in circuit. The other pole of the battery is connected both to the internal electrode of the lower well and to the casing of the upper well. In this case the gradual movement of the ground-water from one well to the other is shown on the ammeter chart, and an abrupt indication of the arrival of the electrolyte at the lower well is also recorded. With this device Professor Slichter has made preliminary tests of the rate of movement of the underflow of the Arkansas River in Western Kansas, and has found rates varying from 3 to 15 feet per day.

The highest recorded velocity of underground water is said to be 144 feet in twenty-four hours, against a previous record of 100 feet. The new record is for water flowing through gravel near Tucson, Ariz. The observations were made by H. C. Wolff, of the Department of Mathematics, of the University of Wisconsin.*

Storer gives the following values for the water-holding powers of various soils. The figures show the percentage of water absorbed in terms of the weight of the dry soil, and were determined by drying, weighing, soaking, draining, and again weighing each sample.

Quartz-sand, rounded edges	26 per cent
Quartz-sand with flakes of mica	32 "
Gypsum (earthy)	27 "
Loamy clay	50 "
White clay	74 "
Yellow clay	68 "
Loam	52 "

* Engineering News, Feb. 1, 1906.

Fertile marly loam	59 per cent
Limestone-sand	29 "
Humus	180 "
Peat	201 "

A word of caution seems proper here. It must be remembered that the above figures show what the sands and soils will *hold*, not what they would *deliver*. No pump could extract that final portion of the contained water which would remain as "moisture," and its quantity would be a very respectable percentage indeed of the amounts given.

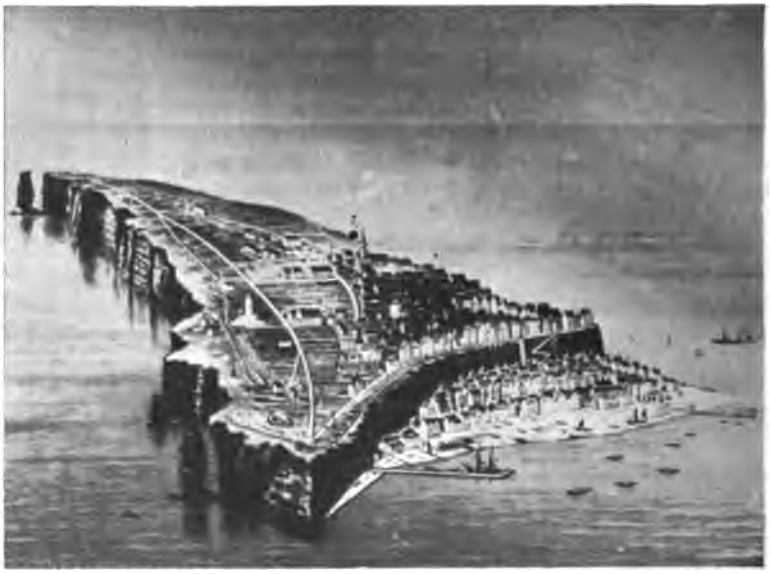
"When a soil is only slightly moist, the water clings to its grains in the form of a thin film. When these soil-particles are brought together, the films of water surrounding them unite, one surface being in contact with the soil-particles and the other exposed to the air. If more water enter the soil, the film thickens, until finally, when the point of saturation is reached, all the space between the soil-particles becomes filled with water, and surface-tension within the soil is thus reduced to zero. Gravity then alone acts on the water and with a maximum force.

"In a cubic foot of ordinary soil the total surface of the soil-particles will be at least 50,000 square feet. It follows that when the soil is only slightly moist the exposed water-surface of the films surrounding the soil-particles approximates that of the particles themselves. If such a mass of slightly moist soil be brought in contact with a like mass saturated with water, the films of water at the point of contact will begin to thicken in the nearly dry soil at the expense of the water-content of the saturated mass. The water will thus be moved in any direction.

"During evaporation the surface-tension near the surface of the soil is increased, and the water is thus drawn from below. In like manner, when rain falls on a somewhat dry soil, the surface-tension is diminished, and the greater surface-tension below pulls the moisture down, even when gravitation would not be sufficient for that purpose." *

* Bulletin 4, U. S. Weather Bureau; also Wiley's "Agric. Anal.," i. 155.

Wherever found, and under whatever circumstances, the water of the ground owes its origin to the rain or melting snow. Attention is called to this point because of a widespread notion that the wells of fresh water often existing in the immediate vicinity of the ocean are fed with sea-water from which the salt has been removed by percolation through the sand of the beach. All along the shore of the Italian Riviera the traveler can see wells dug within 150 feet of the surf. In such cases the fresh



HELIGOLAND

water found originates some considerable distance inland, and the wells intercept it on its way towards an outlet in the sea; in other instances its origin is due entirely to very local rains, and its storage in the loose sand is owing to its being specifically lighter than the surrounding sea-water.

A case of this kind is met with on a little island just east of Heligoland. The island is practically a mound of sand, raised but a few feet above the level of the North Sea, and it is perhaps half a mile long and two hundred yards wide. It was formed and is maintained by ocean currents, and is covered by

"SUNK-WELL" OR "SINK HOLE"
(Water Supply Paper No. 67)

UNDERGROUND SOLUTION-CHANNEL
(Water Supply Paper No. 67)

a most scanty growth of grass. Upon this island several fresh water wells are maintained. Necessarily the water to be secured from such a source is limited in quantity. Under the general caption of deep-seated water we shall see that fresh water may reach the ocean from very distant sources, and under a head so great as to cause a veritable "boiling spring" miles out at sea.

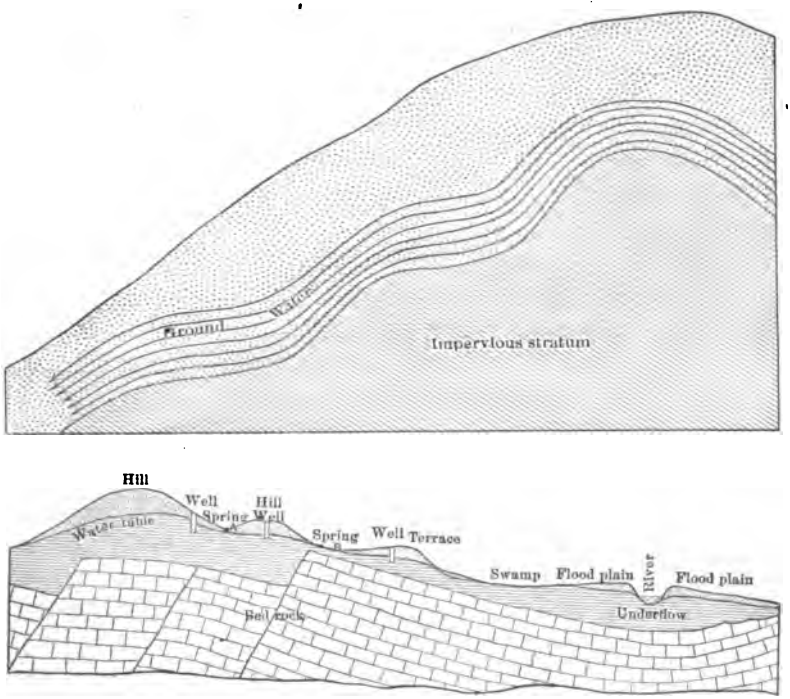
A commonly received conception of the occurrence of ground-water is that it moves in very definitely localized streams or veins, and that, to be successful, a well must be sunk so as to intercept one of these. Of course the conformation of the country may, at times, cause this popular notion to closely coincide with the truth, but a more general description of the occurrence of ground-water would be that of a widely extended sheet, and the expression *water-table* has been adopted with that view in mind.

Underground streams, some of large size, do certainly exist, expecially in limestone districts, but their character would hardly permit of their being classed as typical "ground-water." If considered at all, they should be properly placed under "deep-seated water," although their importance as means of supply is entirely insignificant.

The mean height of the "water-table" (i.e., its distance from the surface of the ground) is governed by the average rainfall and the opportunities for local drainage. The delivery being into the rivers and streams of the district, or into the sea, there is always a slight inclination of the water-surface toward those natural drains, more especially in their immediate vicinity. The seaward slope of the water-table of the south half of Long Island, for instance, is from 8 to 12 feet per mile.

When a well is sunk into this layer of ground-water, and draught by pumping made thereupon, a *cone of influence* is established, whose apex is at the bottom of the well, and whose lateral elements coincide with a new and steeper slope of the surface of the water-table. The steepness of this slope, and consequently the area of the case of the "cone," will in large

part depend upon the character of the soil through which the water is caused to flow. If the grain of the soil be fine, the high degree of friction will greatly impede the passage of the water, and as a result the slope will be steep and the base of



SECTIONS SHOWING RELATION OF GROUND SURFACE, WATER TABLE AND BED ROCK.
(After C. S. Slichter, Water Supply Paper No. 67.)

the cone contracted, while the reverse conditions will obtain in a soil of open, sandy texture.

Throughout the semi-arid region of the great Western plains the ground-water and deep-seated water development have received a very large share of attention. If it were true that the "underflow," which unquestionably exists there, constantly received inexhaustible reinforcements from the mountains farther west, it would be very apparent that sterile wastes

might quickly be transformed into fertile meadows by the sinking of wells and irrigation on an extensive scale.

It is erroneously held by many otherwise well-informed people that the ground-water supplying the wells of large portions of the great plains of Colorado, Kansas, Nebraska, Wyoming, and Texas is derived from the melting of the snow on the Rocky Mountains; but, as is shown in the reports of Professors Hay and Hill,* "the great body of the area of the plains is cut off from contact with the mountains by deep river-trenches, which make it impossible for them to receive any benefit from the melting of the mountain snows." This is shown graphically on the next page.

Referring to *the underflow* of the semi-arid region, Follett says:

"I was detailed to collect facts bearing on the possibilities of general irrigation from the underground waters. Many facts were gathered, all tending to confirmation of the assumption that the sheet-water, broadly speaking, receives none of its supply directly from the mountains. This is important, as tending to assist in computing the possible supply. Its source must be the western portion of the great plains, with very little if any, foot-hills drainage. Here the rainfall is light, and the soil in general not such as will freely imbibe water, and the evaporation is rapid. All these conditions tend to show that the supply of underground water must be limited."

He concludes that—

"(1) The underflow is not supplied from the snow or rainfall of the mountains.

"(2) Its rate of movement in the sand is very slow, hence

"(3) The amount which may be drawn from it without permanently lowering its level is small.

"(4) Each farmer on the great plains whose land is underlaid by this sheet-water at a moderate depth can hope to obtain by pumping water enough to irrigate a small garden and truck-patch, say two to five acres, but

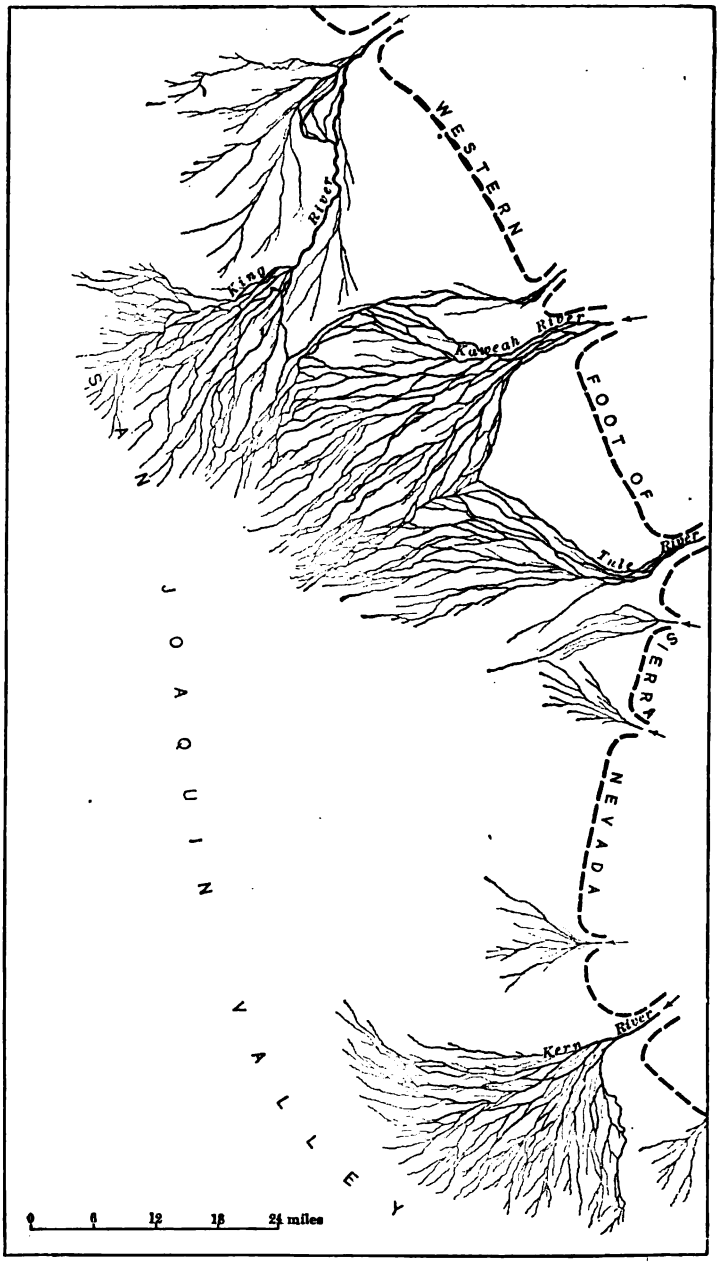
"(5) The supply is not such as to warrant large expenditures in constructing plants intended to obtain water sufficient

* Senate Doc. 41, part 3, 52d Congress.

for general irrigation. Even if momentarily successful, as a plant would be drawing down the surface of a lake with no outlet, the supply will be exhausted. In other words, the water-surface will be permanently lowered, and disaster to the irrigation-plant will follow.

Slichter * describes "the underflow" in these words: "The groundwater after starting on its journey toward the river valley may not after all find its way immediately into the channel. Sometimes it takes a general course down the thalweg and toward the sea within the porous medium itself. This movement may be so great as to constitute a large underground stream, scores of feet in depth and miles in breadth." Such a state of affairs might exist in connection with many streams, so the expression "underflow" must not be considered as applying to the western United States alone. The velocity of flow of this underground water is very small and is largely determined by the degree of fineness of the material through which it passes. The flow may, or may not, add to, or subtract from the water of the surface stream.

* Water Supply Paper No. 67.



SHOWING DELTAS OF DISAPPEARING STREAMS AS THEY LEAVE THEIR MOUNTAIN CANYONS

(Courtesy of C. S. Slichter.)

Salbach * reported the water of the underflow of the Elbe to be distinctly different from that of the river itself; and that in bore holes put down through the river bottom the water rose six inches above the river water-level.

When the entire surface stream is drafted off to the underflow, then we have an instance of a *disappearing stream* such as may be seen in the Coast Range, California. (See page 383.)

"Sunk wells" are at times formed by the caving in of the surface of the ground, and the consequent exposing of pools of water in a country apparently destitute of moisture. Such cavings are due to removal of soluble material from beneath the crust by the solvent action of the "underflow." Pools of this description have been formed in western Kansas.† (See page 379.)

Springs such as are so often seen issuing from the hillside are the primitive means by which the water of the ground first became available for use by man, but, inasmuch as they became insufficient to meet the demand, artificial openings of one kind or another were made whereby the buried water could be reached.

When the conditions prevailing in the district do not favor the development of a spring on the side or at the base of a slope, the time-honored manner of tapping the underground supply is to sink the ordinary *domestic well* into the water-table.

To avoid surface contamination entering the well the construction illustrated herewith ‡ is serviceable. The well top is closed and is raised above the ground surface, while the joints of the tile-pipe casing are laid in cement down to the water-level. This arrangement insures a maximum filtering action of the intervening soil.

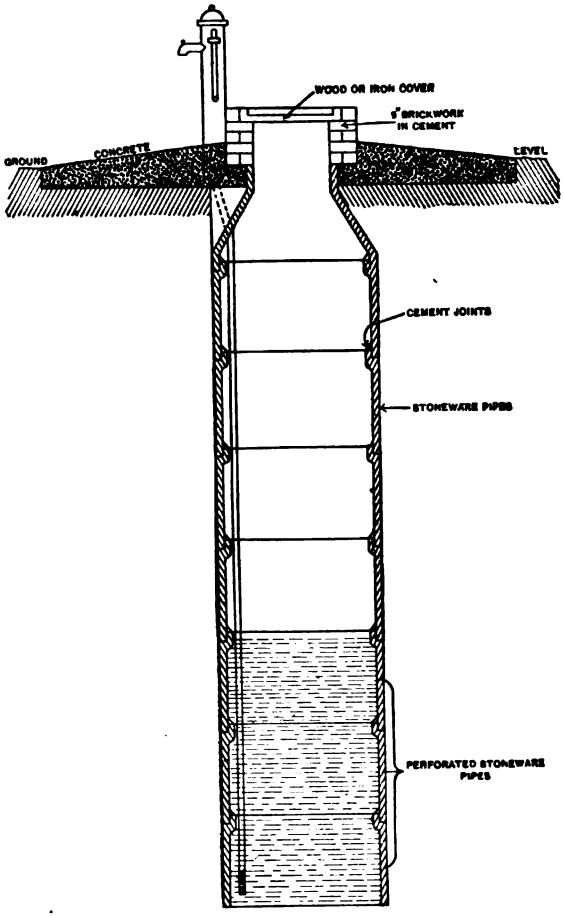
The self-sinking wells at Lagos, West Africa, are constructed by piling rings of concrete, about one foot thick, one above an-

* Am. Soc. C. E., xxx. 293.

† Senate Doc. 41, part 4, 52d Congress, p. 30.

‡ See J. Sanitary Institute, xxii. 515.

other, with the bottom ring arranged with a cutting edge. The inner diameter is about four feet and upon excavating the sandy soil from the interior the weight of the superimposed concrete rings forces the cutting edge to shear vertically while



TILE-LINED DOMESTIC WELL

tne miter throws the sand inwards and the whole structure sinks like a caisson. No disturbance of surrounding soil thus occurs and consequently there is no interference with its efficiency as a filter.*

* J. Roy. San. Inst., xxv. 1064.

The character of ground-water from a locality beyond the reach of human contamination may be judged from the following analysis of a spring-water from the Adirondack Mountains:

Odor, taste and color	none	
Free ammonia	none	
Albuminoid ammonia	.02	per million
Nitrogen as nitrates	.28	"
Nitrogen as nitrites	trace	
" Required oxygen "	.25	"
Chlorine	2.	"
Turbidity	none	
Alkalinity	47.5	"
B. coli communis	none	
Bacteria per cubic centimetre	1.	"
Total solids	83.	

Wells of the domestic type but of large size are not infrequently used for city supply; thus Schenectady, N. Y., secures its water from three wells each 43 feet deep. Two of these are circular in section with diameters of 50 feet, and the third, from which the water is pumped, is of " gallery " shape, being 60 feet long and 8 feet broad.

The well nearest the " gallery " is located 51 feet away and is separated by but 7 feet from the third well. No pipe connection exists between these wells, the water passing between the three of them by percolation only.

Upon the occasion of a large fire, when the pumps were run at the rate of eighteen million gallons per day, the water-level in the " gallery " fell 16 inches, and in the circular wells 10 inches, and 6 inches, respectively. It is a question if the expense of sinking the circular wells was warranted in view of this experience. In all probability the " gallery " would receive as much, or nearly as much, inflow from the surrounding water-table if the wells did not exist.

In another city the writer found a large circular well of the above type receiving drainage material, as indicated by the chemical analysis, and yet showing no pollution from a bac-

METHOD OF RAISING GROUND-WATER FROM A SHALLOW WELL, TANGIER, MOROCCO.

teriological examination. The " sanitary survey " was unsatisfactory. This is but another instance of the risk attending the founding of an opinion as to the quality of the water upon one line of inquiry alone.

Large wells of this kind, having great storage capacity, are often heavily pumped during a few hours per day and are then allowed to rest for refilling. By this method of use the " cone of influence " in the water-table assumes a steeper grade, the velocity of inflow increases and if there be a source of pollution in the vicinity there will be greater chance of its affecting the well-water than if the filtering power of the soil were not intermittently overworked.

It is not especially rare to find waters of greatly varying characters at different depths in the same well flowing from distinct and perhaps widely separated strata. The following case is of a somewhat different character. A city upon one of the Great Lakes sank a trial well upon a sandy peninsula extending some miles into the lake, in the hope of obtaining filtered lake-water therefrom.

Samples of water from depths of 29 feet and 57 feet were submitted to the author for analysis, with results as follows (parts per million):

	Samples from		
	29 Feet.	57 Feet.	Open Lake.
Free ammonia	0.28	too high to read	0.071
Albuminoid ammonia	0.189	too high to read	0.078
Chlorine in chlorides	1.5	61.	5.
Nitrogen as nitrates	trace	trace	none
Nitrogen as nitrites	0.0025	none	none
Required oxygen	5.35	10.1	1.75
Total solids	137.	753.	131.

The sand appeared to be of the same quality throughout the depth of the well, except that the lower layers ran much higher in chlorides. The two waters from the well differed not only from each other, but also from the water of the lake itself. Water from the deeper portion undoubtedly owed its char-

acter to the soluble material in the sand in which it had been stored, while that from the more superficial sand represented a dilution of the same by the more or less recent rainfall which rested upon the denser layer below.

Attention should be called to the fact that new wells and recently developed springs make but a poor showing from the analytical standpoint. Examinations of their waters are worthless, especially from a bacteriological point of view. Gas-forming bacteria are almost certain to be discovered and altogether the chances for an adverse report are many. Weeks, or better, months, should intervene before submitting a "newly developed" water to analysis.

A curious instance of the contamination of ground-water with mineral impurity is reported by Haworth.* In writing of Cherokee County, Kan., he says: "The well- and spring-waters before the mines were opened were first class, but as soon as the mines were opened all was changed, and the older the mines the worse the water. Animals of all kinds began to be seriously affected."

The mineral deposits of the section of country above referred to consist largely of zinc blende, and the development of the mining properties permits of a ready oxidation of the zinc sulphide to soluble salts. Zinc-bearing spring-water from the neighboring portion of Missouri is reported as containing as much as 327 parts of zinc sulphate per million parts of water.

It is very well known that free sulphuric acid at times occurs in the spring-waters of localities where pyrites is exposed to oxidation.

Arsenic is occasionally a constituent of spring-water, for example, the water of the Maxquelle, at Dürkheim, contains as much as 17.4 parts per million. Manganese associated with iron is quite common in the ground-waters of some districts, especially northwestern Missouri. Most instances of the existence of metallic salts in a water should, however, cause it to be classed under the general head of "mineral waters," and such are here manifestly out of place.

* Am. J. Sci., xliii. 418.

For the delivery of large supplies the ground-water cannot by conveniently tapped by ordinary dug wells, so that recourse is had in such cases to what is known as "driven wells," set within suitable distance of each other, and coupled to a general main through which the water is drawn by the pump.

Each well is but an iron tube, two inches to over a foot in diameter, perforated at its lower extremity, which is sunk through the soil to the water-bearing layer below. Single wells of this description, surmounted by a simple hand-pump, may be seen in some instances, replacing the domestic well in the country door-yard, but the type is commonly met with in "gangs" of considerable number of units for the supply of cities or towns.

At Brooklyn, N. Y., slotted tile strainers, 20 to 40 feet long, are sunk in tubing previously put down, the space between the two filled with gravel and the casing withdrawn coincidently with the filling process. By the use of tile, corrosion and electrolysis are avoided and greater permanence is secured.

A method of sinking wells by the use of live steam was patented a few years ago, and, under some conditions of soil, may show considerable saving in first cost.

A hole some 20 feet deep is first bored with an auger, and in this is inserted a 6-inch heavy galvanized wrought-iron pipe, its lower 6 feet being perforated with $\frac{3}{8}$-inch holes. Inside of this is placed a 2-inch steam-pipe, with a nozzle formed at its lower end, and steam at 150 pounds pressure from a large boiler admitted. Sand, soil, stones, and steam escape from the 6-inch pipe in a continuous stream, and the pipe rapidly descends, being constantly turned by a man with heavy pipe-tongs at the mouth, and extra lengths added as necessary, until a supply of ground-water is found.

By whatever method the "driven well" is sunk, its mode of action is entirely similar to that of the common domestic well, from which it differs only in diameter, and it is supplied by the ground-water of the district in the same manner as its longer-known progenitor. There is, in short, nothing gained in the majority of cases from the supposed exhaustion of air by

DRIVEN-WELL PLANT, BROOKLYN, N. Y.

the action of the pump. Much has been claimed under this head, and it has been urged that the zone of influence always widens rapidly under "suction" from an air-tight well; but it must be remembered that "air-tight" is a term which can be usually applied to the well only, and not to the ground overlying the zone of influence. The porous soil will unquestionably admit all the atmosphere required, and consequently the flow of water will be determined by those forces, and those only, which govern in the case of wells of the ordinary type.

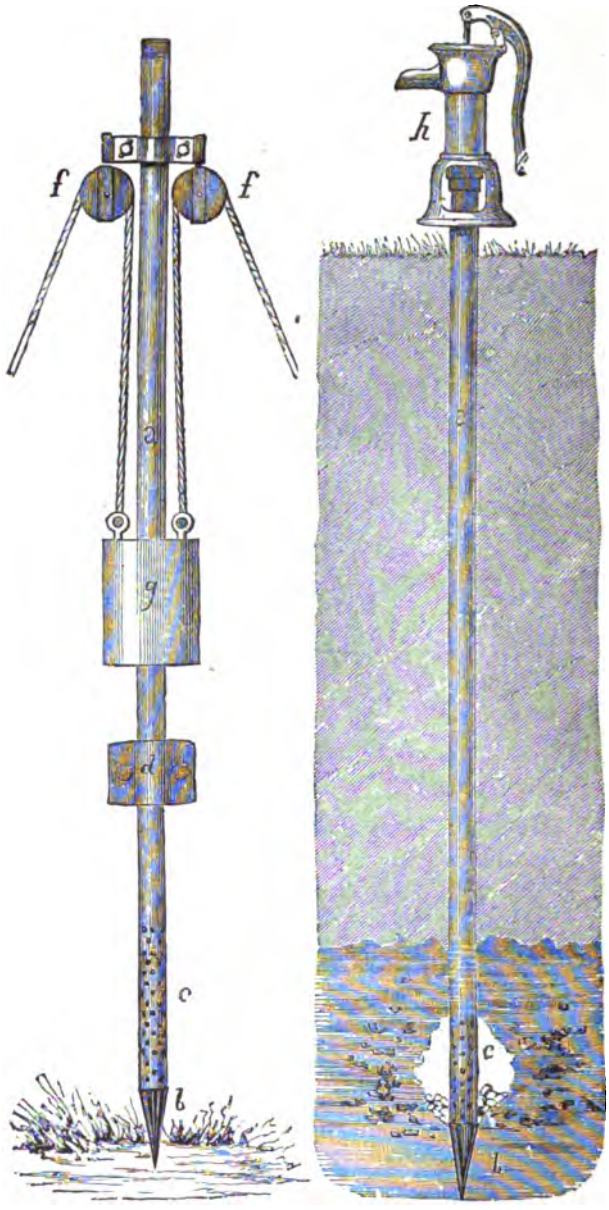
When, however, the well passes through an extensive layer of impervious clay, and taps a water-bearing stratum beneath, then the opportunities for a development of the advantages of "suction" reach their maximum.

If the water-level in a well be lowered by pumping, the capacity of the well to deliver water is progressively increased. For one 6-inch well under discussion, which was sunk to a depth of 100 feet in a 200-foot stratum of water-bearing sandstone, C. S. Slichter found the following delivery in cubic feet per minute for the several distances in feet that the water was lowered: *

1	foot	lowering.....	1.8	cubic feet	delivery
2	"	.....	3.9	"	"
4	"	.....	7.2	"	"
8	"	.....	14.7	"	"
12	"	.....	22.1	"	"
16	"	.....	29.5	"	"
20	"	.....	36.9	"	"

He points out the wisdom of carrying the bottom of the well sufficiently far below the surrounding normal water-level to allow of material lowering of the water in the well itself; and he further shows that in a well such as the above "if the size of the discharge pipe does not offer material resistance to the flow of the water" the capacity in cubic feet per minute will vary as follows for a varying diameter of well:

* "Movements of Ground-Water," 19th Annual Report U. S. Geol. Sur., p. 284.



DRIVEN WELL (FRENCH FORM). (Garban.)

2 inch	31.90	cubic feet
6 "	36.94	"
12 "	41.45	"

As cost increases with diameter these figures are worthy of note. Should the well be a " flowing " one under high pressure, then of course the item of frictional resistance in a small pipe casing would have to be considered.

Great dependence is often placed upon the driven-well system as being an arrangement by which pure water is guaranteed by the thoroughness of natural filtration on a large scale. There is one weak point in this view which must be always kept in mind and guarded against. The filter is a good one without question, but if damaged it is beyond repair and it therefore should be treated with corresponding care. The danger is that an additional supply is frequently sought for by an increase in pumping capacity rather than by an extension of the plant. As a result the wells are over-forced, there occurs undue lowering of the local water-table, rapid flow of water toward the exhausted locality causes channel-ways to form in the subsoil, and surface-water consequently enters the wells without suitable purification. Such a condition of things being once established, no remedy is available.

Writing about a large city plant, Breneman says: " Seven million gallons of water are daily drawn from a system of a hundred wells, varying in depth from 45 to 100 feet, and covering a line about 400 feet in length. Such a yield corresponds to a total rainfall of 32 inches a year upon 3000 acres, or, roughly, represents the same annual rainfall upon all of the land within a radius of $1\frac{1}{4}$ miles from the pumping-station. Owing to the sudden demand for this water the soil-waters must be continually drawn downward in the vicinity of the pumps, and the nearer regions must be more effectually drained than the more remote. The predicted consequences are abundantly realized. Shallow wells in the neighborhood are wholly or nearly dry since the pumping-station has been opened. A swamp, formerly existing about the station, has been dried up. The

subsoil of a cemetery, 370 yards distant, which offers frequent opportunities for observation, is said by the sexton to be much drier than heretofore."

A fact often lost sight of is that driven wells, so far as a permanent supply is concerned, are dependent upon the amounts of rainfall, "run-off," evaporation, and plant requirements. There is not, contrary to popular conception, an underground reservoir from which unlimited quantities of water may be pumped. It is true that a reserve storage exists, that may be drawn upon in time of drought, but Nature keeps a strict account of such matters, and the deficiency created in time of need must be made up during the period of plenty; otherwise the delivery of the plant will gradually diminish and ultimately entirely cease.

The result of heavy pumping from the old Liverpool wells resulted in a lowering of the water-table, with infiltration of salt water from the river Mersey.

Galveston, Tex., has a similar and expensive experience. The citizens of that city attempted to extend an excellent driven-well plant which they possessed by increasing the number of wells, and they carried the draught upon the ground-water beyond the point of normal supply. As a result the entire system was damaged by the inflow of salt water from the Gulf.

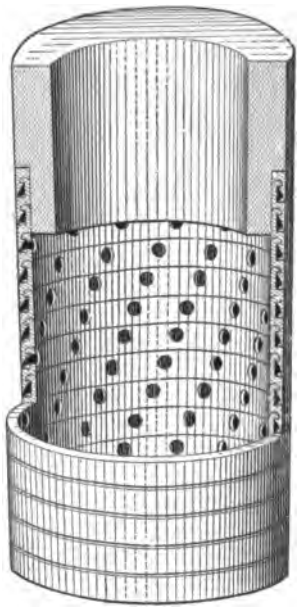
One very material advantage possessed by a driven well over a dug one is that it can be sunk deeper in the water-bearing sands at small expense, and, with a long strainer, can take water throughout a great fraction of its length. A dug well, on the other hand, has its construction hampered after water is reached, and its cost per foot is greater beyond that point; so that it commonly has to depend principally upon its bottom for supply, tapping, as it does, only the upper portion of the ground-water layer.

The form of strainer used for this type of well will vary from the simple "well-point" (page 394) to the more elaborate designs such as that described by D. H. Maury, which are put into place after the well-casing has been sunk to the proper

depth, the casing then being pulled back so as to uncover the openings of the strainer and allow the water to flow in.

" The diameter of the holes in the inner wall is in all cases $\frac{3}{32}$ in., while the width of the outer slot is from 0.004 to 0.020 inch. Strainers are listed for all pipe diameters from 2 to 12 inches.

" The openings in the strainer are made larger on the inside than on the outside, to prevent their becoming choked by sand." *



JOHNSON WELL STRAINER.

Although channel-ways may be opened up in the surrounding sandy material by heavily pumping a driven-well plant, it is quite as likely that fine drift may pack in and about the strainer, reducing, if not practically cutting off, the delivery of the well, unless proper attention be given to cleaning it.

The plant at Lowell, Mass., is cared for twice a year. Mr. R. J. Thomas, Superintendent, describes the system as consisting of 345 two and a half inch wells, ranging from 30 to 40 feet in depth, including the strainer at the bottom, which is 36 inches long. Every well has a valve on the pipe connecting it with the suction main and also a cap on its top, at the surface of the ground.

" The first operation in cleaning a well is to close the valve and remove the cap just mentioned. A brush 3 inches in diameter is then forced down by hand to the bottom of the strainer and drawn out again. The effect of this is to loosen the deposit on the sides of the well. The next step is to screw a No. 6 Douglas pitcher pump on the top of the well and pump the same hard for about five minutes. Then the pump handle is raised and the water in the pump is allowed to run back, which together

* Engineering News, March 8, 1906.

with water poured from pails into the well, has a still further cleansing effect. This is followed again by a vigorous use of the pitcher pump for a while. Thus the process of cleansing and then pumping, which we call " tripping," is continued until the water comes from the well clear.

The total labor-cost for cleaning 345 wells is $652; cleaning them twice a year, as we do, of course, costs double that amount, or $1304.

When preparations are being made to sink a gang of driven wells, consisting of a considerable number of individuals, one of the first questions that must be considered is the distance apart the wells should be placed so as not to draw from one another's territory. This is a point upon which no fixed rule can be given. In the Brooklyn plant, to which reference has been made, the wells are 20 feet apart, but the local conditions may cause this distance to be materially increased in some cases. It is often poor economy to place wells nearer than 50 feet from each other, and at times even 100 feet may be the suitable distance.

A good practice to follow would be to sink two wells at what judgment would indicate as a proper interval, pump from one of these, and, if the second be too much affected by such pumping, increase the distance for the third well, and so on until the proper distance be determined.

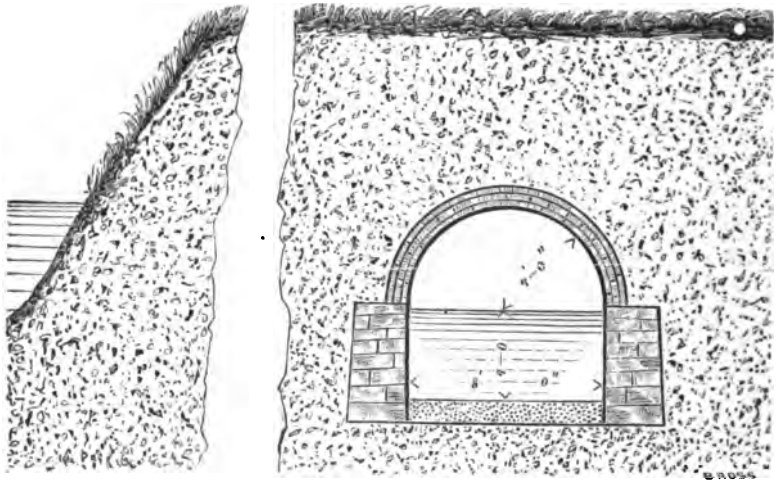
Closely related to the well systems already spoken of, the " infiltration-gallery " stands as a widely used method of securing the water of the ground.*

Such a gallery is really but a dug well with one very long horizontal axis. Its position is usually near, and parallel to the banks of some stream, such a site being often chosen with a view of securing its supply from the water of the river. Except under unusual circumstances, however, the water reaching the gallery comes from the landward side, and is the ground-water of the district for which the river is the drain.

* See pages 399 and 400.

NEWTON WATER WORKS—5 FEET BY 4 FEET 8 INCHES WOODEN COLLECTING GALLERY, 1890.

Rivers may indeed diminish in volume as they flow onward, and may even entirely disappear by sinking into the ground, as we have seen, but this condition is distinctly exceptional. A river is commonly to be considered as a drain, into which water is received, but from which none flows. To such an extent is the bed of a river usually rendered impervious to the outward passage of water by the accumulation of fine silt, that an old authority goes so far as to say: "If you dug a well in the middle of a river, and kept out the surface-water, it is doubtful if you would get the river-water in your well."



FILTER GALLERY. (Nichols.)

The writer found the following results for water from a well sunk upon a sand-bank in a river, and for water from the river itself:

	Parts per million.	
	River.	Well.
Free ammonia	.045	.045
Albuminoid ammonia	.155	.0
"Required oxygen"	6.	2.7
Chlorine	2.9	4.3
Nitrogen as nitrates	.337	.127
Nitrogen as nitrites	0.000	0.000
Total residue	131	100.5

Also the following results for the water of a small filtering-gallery within 20 feet of a large river, compared with the water of the river itself:

	River.	Gallery.
Calcium carbonate.....	26.8	163.0
Calcium sulphate.....	19.4	80.0
Magnesium carbonate.....	0.0	38.6
Iron.....	0.7	2.5
Chlorine (as chlorides).....	4.0	22.0

Although wells near rivers commonly do not draw river water, they are nevertheless liable to be contaminated thereby during periods of flood.

Dependence is constantly laid upon the excellent filtering powers of these underground galleries, and they justify it during the earlier periods of their use, but, considered as a filter, such a device is beyond cleaning and repair; it may clog, or, on the other hand, ruinous channel-ways may follow heavy pumping. In the first instance no water, and in the second instance polluted water, may result.

A development devised for the recovery of underground water that is chiefly found in the western parts of the United States is what is termed the *subsurface dam*. Its name is almost a sufficient description. If a trench extending to bed-rock be dug across a dry "wash" and such excavation be then filled with concrete, and the wall be carried upward, the dam so formed necessarily arrests the underflow and water will collect upon the up-stream side. The illustrations taken from "Water Supply Paper No. 67" show the dam under construction and also the benefits following its completion.

The circular collecting wells shown in the dam wall serve as intakes from which the distribution mains start.

Amsterdam, like several other cities of Holland, derives its water from the "Sand-Dunes"; irregular round-topped sand-hills, which have been erected by wave and wind action along the whole of the Netherlands coast. In height they at

SUB-SURFACE DAM DURING CONSTRUCTION.
(Water Supply Paper No. 67.)

COMPLETED DAM AND LAKE FORMED THEREBY

times reach 160 feet, but average much less, while the breadth of the range is very variable. Near the sea they are devoid of vegetation, the surface of the sand being moved to a considerable degree by the action of the wind, while further inland grass appears and crops of various kinds are raised.

The particular section, near Haarlem, whence Amsterdam draws its water, is composed of rather loose sand in which "reed-grass," is planted in tufts by the city water department, to keep the sand from shifting. The rain falling upon this territory each year amounts to about 28 inches.

A natural "run-off" of the "Dunes" is very low and the absorption by vegetation still less; 64 per cent of the annual rainfall sinks into the sand.

The area drained by the collecting system of Amsterdam is about 7500 acres and the volume of water secured amounts to some eight million gallons daily. Open canals, very similar to small railway cuts, wind between the sand-hills and gather the ground water of the district into a collecting basin, whence it is pumped to Amsterdam, some 14 miles away.

The side slopes of these collecting canals are $1\frac{1}{2} : 1$, and although the cross-sections are not all of the same dimensions a good idea of their general size may be obtained from the views shown herewith. The depth of water carried in them is now about 6 feet. The aggregate length of the canals is about 16 miles.

The general level of the local water table has been lowered from 12 to 15 feet since 1853 by the operation of the Amsterdam water system; the case being similar to what has been observed in the chalk wells of London, namely, more water has been removed than could be replaced by the annual rainfall. Now, however, the delivery is fixed at a figure not to exceed the rainfall, and consequently the level of the water-table is held constant.

The opportunity for the contamination of well-water, particularly that of the common domestic well, is often great. On another page attention was called to the lack of a proper

SAND DUNE, HOLLAND.

COLLECTING CANAL IN SAND DUNE, HOLLAND.

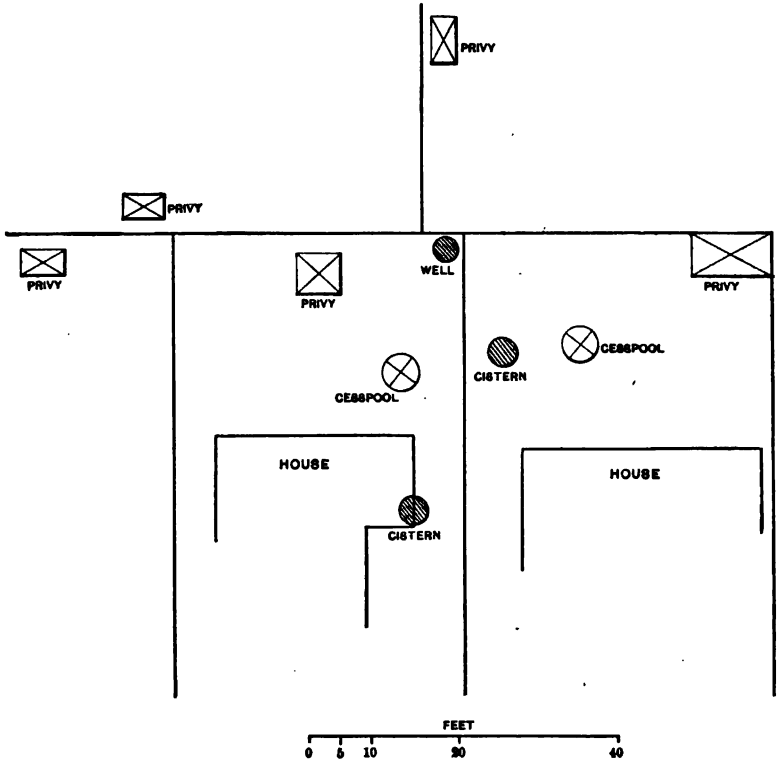
conception of the right location for the house-well among many of our rural people. The author has elsewhere referred to an instance where the well was entirely covered by a huge manure-heap.

In their Sixth Report the English Rivers Pollution Commission state the case quite graphically:

COLLECTING CANAL IN SAND DUNE, HOLLAND.

"The common practice in villages, and even in many small towns, is to dispose of the sewage and to provide for the water-supply of each cottage or pair of cottages upon the premises. In the little yard or garden attached to each tenement or pair of tenements two holes are dug in the porous soil; into one of these, usually the shallower of the two, all the filthy liquids of the house are discharged; from the other,

which is sunk below the water-line of the porous stratum, the water for drinking and other domestic purposes is pumped. These two holes are not infrequently within 12 feet of each other, and sometimes even closer. The contents of the filth-hole or cesspool gradually soak away through the surrounding



WELL SURROUNDED BY PRIVIES, RHODE ISLAND.

soil and mingle with the water below. As the contents of the water-hole or well are pumped out they are immediately replenished from the surrounding disgusting mixture, and it is not, therefore, very surprising to be assured that such a well does not become dry even in summer. Unfortunately excrementitious liquids, especially after they have soaked through a few feet of porous soil, do not impair the palatability of water,

and this polluted liquid is consumed from year to year without a suspicion of its character, until the cesspool and well receive infected sewage, and then an outbreak of epidemic disease compels attention to the polluted water. Indeed, our acquaintance with a very large proportion of this class of potable waters has been made in consequence of the occurrence of severe outbreaks of typhoid fever amongst the persons using them."

The reckless manner in which a domestic well is frequently surrounded by sources of great pollution is here shown in an illustrated form from a Rhode Island case reported by E. W. Bowditch.

One public well, which the author succeeded in having closed after much difficulty, was fouled by cesspool infiltration to a large extent, yet because of the coolness and sparkle of its water it was widely popular, so much so that its final closing had to be accomplished after midnight to avoid resistance.

As an instance of excessive pollution the following analysis is given of a well-water from a summer resort in northern New York. The water was in daily use for all domestic purpurposes, was presentable to the eye, palatable and popular:

Free ammonia	.075
Albuminoid ammonia	.04
Nitrogen in nitrates	11.4
Nitrogen in nitrites	.004
Chlorine	40
Total solids	566
B. coli communis	present

Upon making the "sanitary survey," the conditions surrounding this well were found worse than even the Rhode Island case already quoted.

In some cases the unsanitary arrangements causing the trouble receive more or less support from the law.

In many of the towns of Ohio the local boards of health have determined the minimum distance to be allowed between a well and an uncemented privy-vault, and such distance has been most commonly fixed at 50 feet. The permitted

distance for the town of Norwalk, a place of 8000 inhabitants, has been published as 25 feet, while at Bond Hill the minimum distance allowed is stated as 20 feet.*

That any such distance of soil-filtration can protect a well from pollution, provided the polluting source be constant in character, is beyond even hoping for, and many instances could be given showing how even considerably greater distances have also failed.

Vaughan made sundry experiments touching upon this point; he says:

"In order to ascertain to what extent soil was contaminated by privy-vaults I dug down near a privy-vault which was situated on the outskirts of the town and isolated, so that there were no other known sources of contamination around; I dug down a foot behind this privy-vault and took up some soil 3 feet below the surface to determine the amount of organic matter in it; then I went off 6 feet and did the same thing, then 12, then 18, then 24, then 30; and, without going into detail, suffice it to say that the contamination of the soil from that single privy, built upon nearly level ground, could be detected 50 feet from the vault plainly. This was determined by comparing the amount of organic matter in these different samples of soil with other soil of the same kind where there were no known sources of contamination." †

As serious a case of contaminated ground-water as can be quoted was responsible for the Maidstone typhoid epidemic, in 1897.

Maidstone is situated upon the Medway River, but the water with which the town was supplied came from underground sources, being developments of a number of local springs so situated as to be utilized in three several groups. It was one only of these groups that had its water infected, and the cause of such infection is the interesting point in the case.

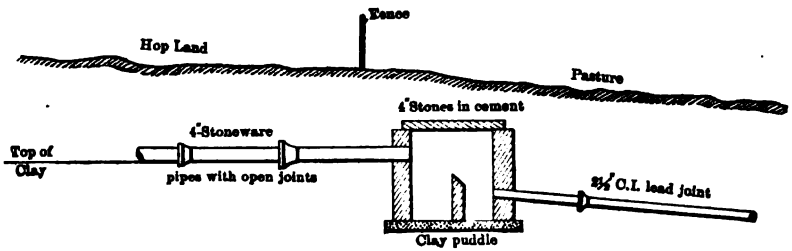
The present municipal supply is derived from deep wells and

* See Report Ohio Board of Health for 1892.
† Ypsilanti San. Convention, July, 1885.

from galleries driven into the chalk along the plane of its junction with the underlying clay, and the water so secured is excellent, but our interest is centered in the conditions as they existed in the summer of 1897.

At that time the city's water was obtained from the ground-water of a highly cultivated district where the soil is often of stiff clay, capable of ready desiccation, with formation of deep soil-cracks during periods of little rain. Through such a dried and fissured soil water can pass rapidly, and in relatively large streamlets, without securing the full advantages of efficient filtration.

Plenty of opportunity would be given for such polluting material as might be thrown upon the ground-surface to pass



CROSS-SECTION SHOWING COLLECTING DEVICE.
(Maidstone, England)

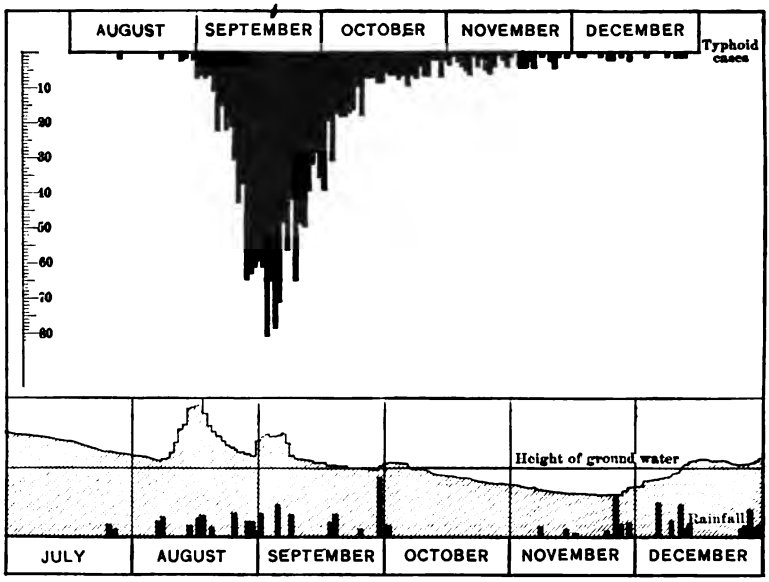
the upper soil in times of rainfall following relative dryness and reach the tile collectors resting upon the clay bed a few feet below. As to what kind of pollution might occur upon such surface, let it be said that the whole district is heavily manured, and that the staple is "hops," a crop whose method of harvesting presents conditions both peculiar and dangerous.

Hops ripen at Maidstone in the latter part of August, and the crop is gathered by a small army of "pickers" recruited from the slums of London. During the picking season these people come down in families and settle temporarily upon the land, a large number of them living in the open, covered by whatever shelter can be secured.

From the character of the Maidstone "pickers" it is easy to conceive that typhoid might be carried to the hop-fields,

and, if so carried, abundant opportunity would be given for infection to pass into the local ground water during periods of drought followed by rain. Dejecta deposited upon the surface would surely be washed by the first rain into the deep cracks formed in the clay soil through the influence of desiccation.

In 1897 the cracks in the Maidstone soil were well developed



SHOWING THE AMOUNTS OF DAILY RAINFALL (IN INCHES), THE VARIATIONS IN LEVEL OF THE SUBSOIL WATER (IN FEET) AND THE NUMBER OF TYPHOID CASES.

The latter are charted so as to make the first of September coincide with the middle of August, thus allowing for the period of incubation.

because " from June 29 to August 6 there had been no rain save on July 26 and 27," and then only 0.21 inch.

Heavy rain fell on August 7 and 8, the ground-water level rose rapidly, and two weeks later the typhoid epidemic began. Dr. M. A. Adams pointed out that the sudden high-water level was due " to the highly desiccated clay being unable to readily absorb so much moisture." Later, however, " notwithstand-

ing occasional rainfall," the water level began to decline because of increased power of absorption on the part of the soil, and subsequently the heavy rains of the end of August caused a second rise of ground-water, which, allowing for the two weeks' incubation, corresponded with the climax of the epidemic.

The lesson for us lies in the manifest relation existing between a polluted surface soil and the underlying ground-water when the former becomes dry and fissured by prolonged drought.

In view of the present interest taken in the hypochlorites for use in water disinfection, let it be said that subsequent to cutting off the infected water, the mains at Maidstone were flushed with a solution of "chloride of lime." The result so far as disinfection went was satisfactory, but the "dose" used was far larger than was necessary.

No less than 583 grains of "bleaching powder" per United States gallon of water (equivalent to 204 grains of available chlorine), in other words, a 1 per cent solution, was the strength proposed for employment, but even this enormous dose was exceeded through an oversight, and the solution actually used was still stronger. It is not surprising, therefore, to learn that "nearly every tap started leaking and had to be re-leathered" and that "the fire-engine, pump-buckets, and delivery and suction hose were entirely destroyed." From our present knowledge of the minute dose of "bleach" that will kill intestinal organisms, we are perfectly willing to indorse the belief of the Maidstone authorities that "no microorganisms of any form that could have obtained access to these pipes could remain alive and active."

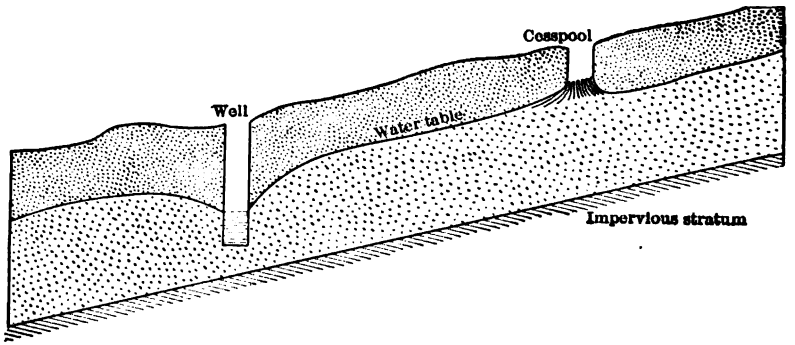
Somewhat similar to that of Maidstone is the instance of the typhoid outbreak at New Harrington which resulted in 275 cases and 26 deaths.* It appears that soil-cracks, due to subsidence caused by coal mines in the neighborhood, permitted

* Report of British Med. Asso. See "Water-borne Typhoid," Hart.

direct flow from farmhouse privy-vaults through some underground feeder to the town well situated some three-quarters of a mile away.

Extract is here made from a report of the writer's upon the question of closing certain city wells:

"As is well known, there are a number of street-pumps in this city, and the water which they supply is cool, sparkling, brilliantly clear, and generally relished. The ground into which these wells are sunk is the old river flood-plain, which extends from the present river to the eastern hills. Into this same soil pours the drainage from many cesspools and privies,



CONTAMINATION OF SURFACE WELL FROM CESSPOOL.

(Water Supply Paper No. 67.)

and the slope of the ground in the centre of the city being away from the river, the natural drift of the ground-water toward a western outlet is to an extent impeded. In consideration of these few facts, can any reasonable person expect to get pure water from such a source?

"It is a fatal error to fancy that because a water has a bright, sparkling, clear appearance and a pleasant taste, therefore such water is wholesome. Carbonic acid gas is what causes the brilliancy and refreshing taste of a ground-water, and to the solvent action of that gas is due the clearness of many waters which hold much organic matter in solution. When it is borne in mind that carbonic acid is one of the prod-

ucts of sewage decomposition, the inference as to its possible source in the case of the present well-waters is not a pleasant one. During the last four years I have at different times examined the waters from several of these wells, and am persuaded that they are contaminated with sewage material beyond a peradventure.

"It is hopeless to depend upon the purifying influence of the intervening soil to protect the wells from privy and cesspool fouling, because soil-filtration, in order to be effective, must be *intermittent*. That is, after a 'dose' of sewage has been added to a soil (and the 'dose' must not be a large one) opportunity for thorough aeration of the soil must follow, or the second 'dose' cannot be purified. With a large and constant flow of polluting material the purifying powers of the soil quickly cease to act.

"It will be objected that these well-waters have been in use for many years without bad results following. Possibly; but it must be remembered that the imbibition of sewage derived from healthy sources may be quite harmless unless it be in too concentrated a form, however undesirable it may be from an æsthetic standpoint. This has been experimentally proven many times. The serious part of it all is that the sewage which contaminates the well-water may suddenly become pathogenic in character and then the well becomes a distributing centre for disease. A city well is always to be suspected, and if, upon examination, its water is found impure, it should be forthwith ordered closed."

No one would attempt to deny the great purifying power of soil; it is only the unreasonable reliance upon such power, and the necessity of recognizing that it is very possible to overload it, that are the points insisted upon here.

Every sand-bed, and broad irrigation plant, designed for sewage disposal demonstrates how great is the value of soil filtration, but the most casual observer of those works will at once note that the sewage is admitted intermittently. Every opportunity is given for aeration and the resulting oxidation and nitrification.

Barwise * makes use of the following good illustration: Weak alcohol, allowed to trickle over twigs upon which are growing the *Mycoderma aceti*, will produce vinegar,

$$C_2H_6O+O_2=H_2O+C_2H_4O_2.$$

VIEW OF WELL AT WALLINGFORD, CONN.

Substituting an ammoniacal fluid, such as sewage, for the alcohol, and the nitrifying germ for the above organism, a similar

* "Purification of Sewage," 104.

carrying of atmospheric oxygen to the oxidizable material will occur and nitrates will result.

A peculiar instance of contamination of a well water occurred near Wallingford, Conn., A six-inch well was drilled through red sand-rock to the depth of sixty-six feet and water of excellent quality raised therefrom by windmill. Later an electric-light plant was erected, which was supplied with power from a gasoline engine. The necessary store of gasoline was contained in a cylindrical tank of riveted steel, three feet in diameter and ten feet long, which was buried just under the ground-surface at a point 130 feet distant from the well; and two gasoline engines were installed in a power-house nearer the well by thirty feet.

About one month after the starting of the engines, a very decided taste and smell of gasoline developed in the water of the well and continued, although with diminished intensity, more than three years after its first being observed.

The information furnished showed that whether from the exhaust of the engines, from a faulty connection or from a leak in the tank itself, several hundred gallons of gasoline had run on to or into the soil within about 100 feet of the well. The writer's opinion was that the injury done was beyond repair and that the well should be abandoned for drinking purposes. When one bears in mind the minute quantity of kerosene which remains upon the hands after handling a lamp and with what certainty a pitcher of ice-water is caused to taste of the oil if the ice be touched by the hands so soiled, it is easy to appreciate how very far several hundred gallons of gasoline would go toward contaminating a ground-water.

Of course the day would come when the last trace of oil would have been washed away, but who would venture to fix the date for its accomplishment?

In such a case as the above the sense of smell is more delicate than that of taste in detecting the presence of gasoline in water, thus it was found that 1 : 30,000 gave a strong odor

but only a slight taste. Dilutions greater than that did not respond to taste although in a dilution of 1 : 180,000 gasoline could still be detected by the nose.

Dilutions of kerosene as high as 1 : 1,400,000 possessed both slight taste and slight odor.

An excellent way to determine the probability of objectionable drainage material entering a well is to place a quantity of a solution of common salt, of lithium chloride, or of fluorescein ($_{20}CH_{12}O_5$) at the point whence contamination is supposed to come. The normal composition of the water being known, there will appear an increase in "chlorides," a spectroscopic test for lithium, or a decided fluorescence in the water if there be drainage from the source in question.

One part of fluorescein will show in 100 million parts of water. A convenient strength of the dye for use is 1 gramme dissolved in a little sodium hydroxide and diluted to one litre with water. Different from sundry aniline dyes which are sometimes used for this work, fluorescein is not decolorized by passing through the ground.

Care must naturally be exercised not to alarm the takers of the water by the use of so intense a coloring agent, and where there is danger of so doing recourse must be had to the employment of the other indicating substances mentioned.

When using fluorescein it must not be forgotten that some waters possess a slight natural fluorescence of their own.*

It may be worth mentioning here that English and American laws are at variance with one another regarding the ownership of underground percolating water, i.e., "ground-water."

Such ownership became definitely settled in England in 1859 by a decision in the case of Chasemore vs. Richards, in which the judgment of the House of Lords was unanimous. "They held that the principles which regulate the right of

* Compt. rendu, 146: 1125; also Chem. Abstracts V: 1810.

owners of land in respect to water flowing in known and defined channels, whether upon or below the surface of the ground, do not apply to underground water which percolates through the strata in no known channels."

Until somewhat recently the principles laid down in this case have never been shaken or departed from. In every case the difficulty has been, not whether the decision in Chasemore vs. Richards was right, but rather in its application to the facts of the particular case.

In a decision of the New York Court of Appeals regarding rights in underground water, in the case of Forgell vs. the City of New York, the decision granted damages to a market-gardener for the diversion of underground water from his land and enjoined the city from continuing to divert the water.

The plaintiff owned farming land in the 26th Ward of Brooklyn, within about 2000 feet of the Spring Creek pumping-station belonging to the water-supply plant. He worked a market-garden and claimed that the operation of the driven wells at Spring Creek reduced the natural flow of water in ditches across his land and caused the failure of crops. Justice Smith of the Supreme Court decided in favor of the plaintiff, and awarded him $6000 damages. The city carried the case to the Court of Appeals, which sustained the decision of the lower court as to damages and also granted a perpetual injunction restraining the city from operating its driven wells at Spring Creek. The court practically decided that if the city wanted water from driven wells, it must condemn and buy all the surface land affected.*

Let us add that the law of ancient Rome allowed a man to dig a well in his field and thereby drain his neighbor's, unless he did so maliciously.

In "Water Supply and Irrigation Paper No. 122," U. S. Geol. Survey, will be found a comprehensive paper prepared by Douglas W. Johnson which meets the demand for information on the relation of the law to underground waters.

* See Engineering News, Dec. 6, 1900.

It gives the common-law rules concerning underground waters and deals with interference, damming, artificial percolation and pollution, and concludes with legislative acts affecting such waters in a number of the States.

Further reference to the relation of the law to water supplies will be found in Appendix B, page 490.

CHAPTER IX

DEEP-SEATED WATER

SPRINGS of small flow, such as trickle out of the country hillside, are properly classified with the shallow wells already spoken of; they furnish "ground-water" only and are of local origin.

Quite another matter, however, are those natural fountains which reach the surface in very great volume, possessed of a temperature radically different from that of the local subsoil, and holding in solution mineral materials that may be quite foreign to the neighborhood. Such water is of distant source, and the gathering-grounds where it originally falls as rain may be very far away indeed.

Picture the outcrop upon some rainy upland of a porous stratum, encased upon either side by strata impervious to water; let the strata be possessed of a moderate dip, then let them be cut transversely at some point below, either by simple erosion or by a geologic fault, and the conditions for a deep-seated spring would be complete. Rain-water falling on the distant outcrop would pass down the porous stratum, picking up soluble material on the way, and would escape as a spring at the point where the strata were broken or eroded.

Notable springs due to geologic faults occur with frequency, but to Americans the best-known instance is to be found at Saratoga, although the water furnished is medicinal rather than potable, and therefore beyond our present consideration.

At the head of San Antonio River, not far from the city of San Antonio, Texas, is situated a mammoth spring of pure water, whose daily outflow is some fifty million gallons. This spring is but one of a group of great springs which "coincide almost exactly with the line of the great Austin Del Rio fault." *

* Senate Doc. 41, 52d Congress.

Near Great Falls, Montana, are the "Giant Springs" which are estimated to flow 400 million gallons per twenty-four hours. The water has a temperature of 50° F.

A curious instance of a spring of great magnitude caused by erosion cutting into the water-bearing stratum is to be found several miles out at sea off the coast of Florida, east of Matanzas Inlet.

There are reasons for believing that the Matanzas spring is due to a bursting of the confined waters through a hole in the upper hard rock-layer. Successful sounding has been accomplished in the spring itself. In its immediate vicinity the ocean suddenly deepens from a depth of 60 to one of 126 feet.

A shipowner familiar with the locality informs the writer that the volume of water boiling up in the ocean at the site of the spring is so large as to prevent a boat remaining on it for more than a moment, as "the boat is washed off from it as from the rapids of a river." The same authority describes the odor of the water as that of a sulphur spring, which is an additional point showing its kinship to the artesian waters of Jacksonville and St. Augustine.

There are several other springs on the same coast similar to this, although not so large.

Fresh-water springs occur in the North Sea in the vicinity of the islands surrounding Holland, and are situated two or three miles from shore. "Similar springs may be found in the Adriatic Sea, near Fiume, Abazzia, Triest, and in other places, so that the surface of the sea is slightly raised up and a whirlpool may be observed." *

Instances are not unknown where streams, or portions of them, disappear to rise again after subterranean flow, thus masquerading as true deep-seated water.

The "source de la Loue," the largest "spring" but one in France, with a flow of 15,000 litres per second, furnishes an illustration of the kind; the discovery of the true character of the water having come about by accident in August, 1901.

It seems that a fire occurred in an absinthe manufactory

* Trans. Am. Soc. C. E., xxx. 300.

located upon the banks of the river Doubs, some seven miles distant from, and at a greater elevation than, the "spring," whereby great quantities of absinthe escaped into the river.

About forty-eight hours later the water of la Loue gave unmistakable evidences of the presence of absinthe.

The conclusion is that the spring represents, at least in part, a subterranean branch of the river Doubs. The outflow from la Loue again joins the Doubs lower down.

Instances are by no means rare of the use of deep springs

LA SOURCE DU LOIRET
(Deep spring supplying Orleans, France.)

for water-supplies of magnitude, such as the one which supplies Orleans, France, but deep-seated water is much more commonly reached by special borings.

Bore holes are made by either the diamond drill or by heavy chisels of solid steel. The former consists of lengths of tubing, ending in the cutting tool which is a short tube holding black diamonds staggered along the periphery of its base. Being rotated this tube cuts its way downward and permits of a solid "core" of rock being recovered for examination throughout the entire depth of the boring.

Such drilling is commonly undertaken to determine the character of the strata upon or through which some engineering work is to be built.

For the purpose of reaching deep-seated water, or oil, it is usual to employ methods using steel chisels, of great weight, which are raised by power and then allowed to fall. The rock is, of course, removed in finely divided form by this process.

It would be going too far to undertake a detailed description of the process of drilling deep wells, yet there are certain facts concerning their cost and rapidity of construction, given us by Professor Carter,* which may properly be here inserted:

"The most difficult rocks to drill through are trap, quartzite, compact fine-grained sandstones, certain clay slates, granites, syenites, and compact hornblende schist, obsidian, etc.

"The softer rocks, such as talcose and chlorite schists, serpentine and other magnesian rocks, limestone, dolomite, hydro-mica schists, and many coarse-grained sandstones, are readily drilled through. The following table will show the thickness of rock pierced by a chisel drill 20 feet long, $5\frac{5}{8}$ inches in diameter, weighing 700 pounds, guided so as to make a round hole:

Locality (Pennsylvania).	Rock.	Rate.
Duffield's farm, on Stony Creek, near Belfry,	Clay slate (Trias)	4½ ft. drilled in 10 hours
Ice company's well, Norristown	Sandstone (Trias)	5 " " "
Kunkle's farm, Valley Green Road, near Flourtown	Limestone (Silurian)	5½ " " "
Wheadley's farm, Chester County	Hydro-mica schist	7 " " "
Wm. Janeas' farm, near William Station	Sandstone (Potsdam)	10 " " "
Roberts' well, Spring Mill	Sandstone (Potsdam)	18½ " 7 hours

"The minerals which compose a rock may be very hard and yet the cementing material may hold the grains so loosely that the drill will make rapid progress through the rock. Sandstone, when composed entirely of silica, or when the cementing material is gelatinous silica, as in quartzite, is extremely hard to drill, but when the cement which binds the

* J. Fk. Inst., September, 1893.

grains is feldspar, which decomposes readily, then the grains are loosely held, and the rock is readily drilled.

"The price of drilling is about $2 per foot in Montgomery County, Pa., for wells six inches in diameter and from 100 to 200 feet deep; this is independent of the character and hardness of the rock.

"Other contracts in Philadelphia have been made at the rate of $2.75 per foot for drilling down to 500 feet, and $3 per foot for drilling below a depth of 500 feet; this does not include the iron pipe for casing, but only the drilling. The six-inch iron pipe (internal diameter five and five-eighths inches) which is used to line the well varies in price from forty to fifty-five cents per foot."

Wells are sunk through the shales and conglomerates of the Catskill Mountains, but not to great depths, at the rate of $2 per foot, and in the Hudson River shale of the upper valley at from $1.50 to $2 per foot. In the oil regions of Pennsylvania the average price is about $1 per foot for the boring alone.

Lower prices are found in California, where the "stove-pipe" method of construction is in use.*

"According to contracts recently let near Los Angeles, the cost of 12-inch wells was 50 cents per foot for the first 100 feet, and 25 cents additional per foot for each succeeding 50 feet, casing to be furnished free. This makes the cost of a 500-foot well $700 in addition to casing. The usual type of 12-gage, double, stove-pipe casing is about $1.05 a foot, with $40 for 12-foot starter with $\frac{3}{4}$ by 8-inch steel ring. A good driller is paid $5 per day, helpers $2.50 per day. The cost of drilling will run higher than that given above in localities where large and numerous boulders are encountered"

The cost of diamond drilling varies very largely with the diameter of the hole and the hardness of the rock.

At Troy, N. Y., the $1\frac{1}{2}$-inch borings, made for inspection purposes along the line of the aqueduct tunnel, averaged 70 feet deep and cost $2.25 per foot. The general character of the rock was hard Hudson River shale.

* Water Supply and Irrigation Paper No. 140.

The presence of boulders, as in a glacial drift, very greatly increases the trouble and expense of well-boring, for the reason that they tend to shift their position during the drilling, thereby throwing the hole " out of true " and causing the tools to jam.

Logs of wood not unfrequently are encountered at great depths, and they always prove obstacles of considerable difficulty.

Bore-holes reaching to great depths:

	Feet.
Domnitz, near Weltin, Germany	3287
Probat-Jesar, Mecklenburg	3957
Sperenberg, near Zossen	4173
Unseburg, near Stassfurt	4242
Lieth-Elmshorn, Holstein	4390
Schladebach	5735
Rybuik, Upper Silesia	6571
McDonald, Penn	7181
Galicia	7300

" The Schladebach well was drilled under the supervision of the Prussian government, in search of coal. It appears that the total cost of drilling the well was $53,076, or at the rate of about $9.25 per foot of depth. The average daily rate of boring was 4.59 feet. The initial diameter of the hole is a little over 11 inches, and the least diameter in the lowest section is about 1.3 inches. Temperature observations which were made showed that at a depth of 5628 feet the temperature was 133.8° F.* Further work on this well has been abandoned."

The Rybuik well is one of the deepest in the world. A difficulty to contend with in so deep a boring lies in the great weight of the boring-tools, which in this instance reached 30,155 pounds. Ruptures were naturally frequent and finally caused stoppage of the work. The cost of the boring was about $2.86 per foot. The temperature observations showed

* Mechanical News, December 15, 1892.

53½° F. at the surface and 157° F., at the bottom, a difference representing an increase of about 1° F. for every 63 feet.*

Professors Chamberlin and Salisbury give the following records of temperature variations with depth.

Locality.	Depth in Feet.	Rise of 1° F.
Sperenberg bore (Germany)	3492	in 51.5 feet
Schladeback bore (Germany)	5630	67.1
Cremorne bore (N. S. Wales)	2929	80
Paruschowitz bore (Upper Silesia)	6408	62.2
Wheeling well (W. Va.)	4462	74.1
St. Gothard tunnel (Italy-Switzerland)	5578	82
Mt. Cenis tunnel (France-Italy)	5280	79
Tamarack mine (N. Mich.)	4450	100
Calumet and Hecla mine (N. Mich.)	4939	103
Ditto, between 3324 feet and	4837	93.4

Concerning these records the authors say:

"It is to be noted that even these records vary a hundred per cent. Very notable variations are found in the same mine or well, and often much difference is found in adjacent records, especially those of artesian wells. Some of these are explainable, but the full meaning of other variations is yet to be found."†

ROCK TEMPERATURES IN DEPTH ON WITWATERSRAND MINES ‡

Rock Temperature at	°F.
1000 feet	68.75
2000 feet	73.53
3000 feet	78.35
4000 feet	83.15
5000 feet	87.95
6000 feet	92.75
7000 feet	97.55
8000 feet	102.35

General rate of increase, 1° F. for 250 feet.

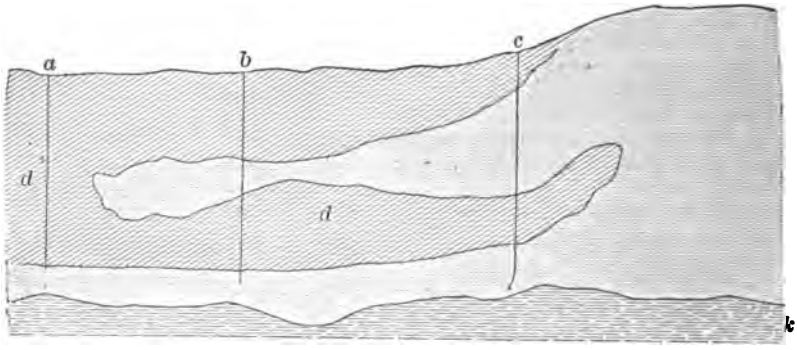
The expression "artesian" has been extended to include deep wells under all conditions, but without proper license, because the term originally came from the name of the French

* See Engineering News, Dec. 31, 1896.

† "Geology," Vol. I., Geologic Processes and their Results, 1904.

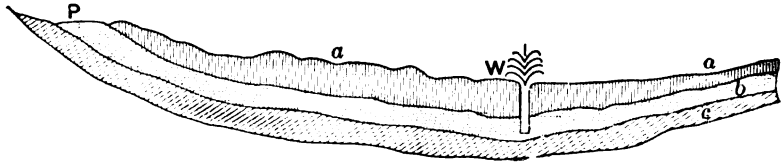
‡ South African Mining Journal, November 12, 1910, p. 417.

province where deep wells were first successfully established in Europe, and such wells were "flowing." It is therefore to "flowing wells" only that the expression "artesian" properly

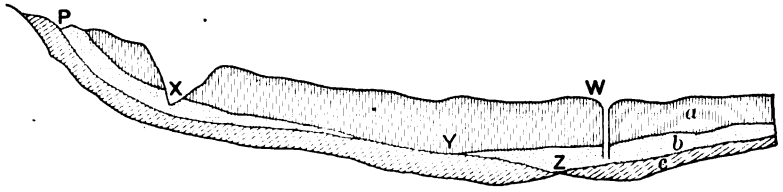


CONDITIONS OF WATER-BEARING STRATA IN RELATION TO OTHER FORMATIONS. (After Robert Hay.)

a, well with one water-level; *b* and *c*, wells with two water-levels; *d*, water-bearing gravel; *k*, impervious shale.



CONDITION FAVORABLE FOR FLOWING WELL. (After Hay.)



CONDITION UNFAVORABLE FOR FLOWING WELL. (After Hay.)

attaches. Wells of this class were first sunk, in Europe, at Lillers, in Artois, in 1126. In the Sahara and in China they have been known for many centuries. Whether, however, the well be a flowing one or one from which the water has to be raised by power, the conditions governing the storage of

such water are essentially the same as have been already given when speaking of deep springs. An outcrop of a porous stratum in a rainy upland acts as the collecting area; this stratum is of moderate dip and is enclosed by other strata, impervious to water, lying above and below.

Unless the strata form a basin or pocket the water of the porous layer will find its natural outlet in spring form where the layer is cut transversely by erosion or fault; but should a well be sunk at some intermediate point the water will rise in the same, or overflow, to a degree dependent upon the head to which it is subjected and to the frictional resistance it encounters; that is, to the elevation of the gathering-grounds above the well, and to the freedom with which the water can flow down the porous stratum and escape through the outlets below.

It must be remembered in this connection that the expression "deep" refers to the non-local character of the water rather than to the depth of the hole required to tap the same. In fact "deep water" may lie very near or even at the surface in some places.

It would be difficult to find an artesian field more deserving of study, or more interesting to the investigator, than the one underlying the southeastern corner of the United States, and which is tapped by the wells of northern Florida, notably that of the Ponce de Leon at St. Augustine.*

No one has better knowledge of that interesting well than Mr. W. Kennish, who was in charge during its construction. The following data concerning the boring are partly taken from private correspondence with Mr. Kennish and partly from his letters to the *Engineering News:*

"The pressure was found to be 17 pounds to the inch, and the flow 10 millions of gallons in twenty-four hours.

"A turbine wheel fed by this flow maintained 120 incandescent lights at 16 candle-power, proving that the well was capable of supplying a force equal to 15 horse-power.

* See also the excellent reports on the deep wells of New Jersey in Report of State Geologist for 1897 and following years.

"Concerning the maintenance of the supply, we are possessed of information upon which to form a judgment. There are now in the town of St. Augustine and its immediate vicinity in the neighborhood of fifty artesian wells varying in diameter from 2 to 12 inches, and exactly the same force exists to-day as when the first well was driven, about ten years since. Another ground for believing that the supply of water is so abundant that it will prove equal to any possible draught upon it by artesian wells lies in the unvarying pressure indicated by the very sensitive gauge of the electrical apparatus operated by the 12-inch well, surrounded as it is by wells on all sides being used in constantly varying quantities. Again, the increase in the diameter of the wells has been attended by more than a porportionate flow.

"While the dynamo was being operated by the 12-inch well a 6-inch well in its vicinity was turned on and off suddenly to test the steadiness of the force, but the closest observation did not detect the slightest trembling of the gauge.

"From these various sources of information we cannot escape from the conclusion that the water under pressure beneath St. Augustine and vicinity is practically boundless.

"The ratio of increase in temperature is very nearly 1° in every 50 feet. This increase was maintained until 86° was obtained at 1400 feet, where the well was stopped.

"Between 520 and 557 feet the rock changes from fossiliferous limestone to conglomerate of chalk, green clay, and a very porous dark fossil stone, largely composed of moulds of shells, the substance of which has been washed out.

"This stratum, of 37 feet in thickness, is doubtless cavernous, through which an enormous flow passes, possibly to find its partial escape in the great ocean spring, five miles seaward from Matanzas, and possibly, still further from the shore, and at greater depth, to swell that great ocean current—the Gulf Stream."

Such successive water-bearing strata as were encountered in the St. Augustine well are frequently observed. Thus in a boring at Fort Worth, Texas, at a depth of 900 feet a stream

of water was struck flowing 170 gallons per minute, with a pressure of 15 pounds per square inch. At a depth of 1035 feet another lower stream was reached of 200 gallons per minute and pressure of 21 pounds per square inch. This second stream having been also cased off, further boring developed a flow at 1127 feet in depth of 245 gallons per minute, with a pressure of 29 pounds per square inch.*

One interesting feature of the deep wells of northern Florida and of the sea-springs off the coast is the great distances the waters must flow in their subterranean passage from the uplands of the interior, for there is no land within a long distance of St. Augustine of sufficient elevation to produce the "head" observed at the wells.

Nearly akin to the Florida wells are those formerly furnishing the public supply for Charleston, S. C., but the pressure and delivery from these latter are not so great.

The direct connection with the sea of the water-bearing layers which these wells tap is shown by the water in them rising and falling with the tide, and it is of special interest to note that the daily fluctuations in the wells do not coincide in point of time with the tides at Charleston, a circumstance to be explained by the hypothesis of a distant connection with the sea.†

A single case, illustrating the danger that may possibly follow the tapping of water-bearing sand under pressure, is mentioned in "Abstracts of Papers," Institution of Civil Engineers: ‡

"The town of Schneidenmuehl, in which the well referred to is situated, lies in the province of Posen, near the West Prussian boundary. In the autumn of 1892 the sinking of the well was commenced, and in May of the next year had reached a depth of 238 feet. From 49 to 52 feet of the upper layers

* Senate Doc. 41, 52d Congress, p. 106.

† There was a famous temple of Melcarth at Gades, containing a mysterious spring which rose and fell inversely with the tide. (Bosworth Smith, "Carthage and the Carthaginians.")

‡ See also Engineering News, December 20, 1894.

were comparatively firm; then a layer of sandy silt was struck, having a thickness of 180 feet. A current of water was used during the boring operations as long as the upward pressure of the ground-water permitted. The tubes had a diameter of 4.72 inches to a depth of 82 feet, when they were reduced to 3.15 inches.

"On reaching a depth of 210 feet a strong current of muddy water issued from the tube. Sinking was continued, when at a depth of 236 feet the flow from the tube ceased; but a strong jet of water, amounting to 220 gallons per minute and containing 5 to 6 per cent of solid matters in suspension issued through the ground at the side of the tube. The cause of the hydrostatic pressure which ejected the water with such force is sought for in the geological formation underlying the town of Schneidenmuehl. This town lies in the valley of the river Kuedow, an effluent of the Netze, and is partially surrounded by hills composed of drift sand, which offer little obstacle to the percolation of any rain-water falling upon them. Upon this sand, however, lies an impervious deposit composed of the more or less clayey sediment left by the river, and this deposit appears to have resisted the pressure of the water until it was pierced during the sinking of the well.

"An endeavor was made to stop the flow of water by drawing the tubes, but this proved unsuccessful, because all solid matter which fell into the well from its sides was at once ejected with the water. Owing to the quantity of sand thrown out considerable subsidences of the surface took place, and the adjoining buildings were seriously damaged. Bags of sand and clay, stones, etc., were thrown into the well; but these were all swallowed up without staying the flow of water. An attempt was then made to dredge out a well or shaft round the tube, but after eight days' hard work a depth of only 2 feet was reached, owing to the quantity of sand driven up from below. It was next decided to drive down several tubes to the depth from which the water came, and this was done; but several of the tubes sank and were lost, so that finally only one tube remained, the minimum diameter of which was 5.9

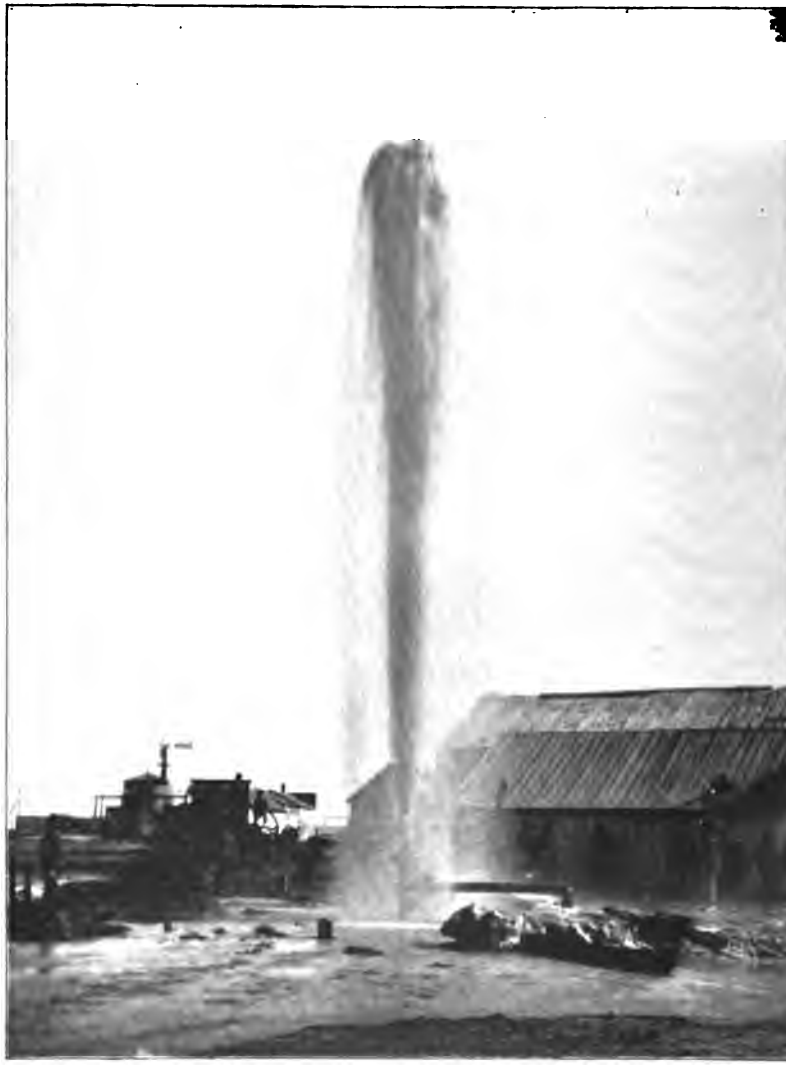
inches. On the 15th of June the ground sank suddenly to the extent of 4.26 feet, carrying with it part of the adjoining houses. After this the flow of water became less, and none reached the surface except through the tube. On the 21st of June tubes of gradually diminishing diameter were fixed upon the main tube, when it was found that the water rose to a height of 65.6 feet above the street-level. By means of taps at different levels the water was gradually cut off, and on the 22d of June it had altogether ceased to flow, and the danger to the town appeared to have been averted.

"On the 20th of September, however, the plug which closed the tube was removed, and the water again began to flow, sometimes containing as much as 20 per cent fine sand. The water forced its way upwards outside the tube, and finally the tube and the whole superstructure of the well sank. The method devised to close the well was to heap as rapidly as possible sufficient earth or sand upon the spot, so that the weight of the layer would counterbalance the upward thrust of the water. An area 69 feet in diameter was cleared, and the six tubes were carefully filled with fine sand. The earth and sand which had previously been brought to the spot were thrown in at the rate of 1.962 cubic yards per minute until a conical mound was formed 6.56 feet high and 69 feet in diameter at its base. This method proved successful, and the issue of water from the bore-hole has now ceased."

Flowing wells at times occur which are not due to hydrostatic pressure, but to the lifting of local water by gas-expansion. Such a case is reported by Professor Hay as occurring in southeastern Kansas.*

The same author also refers to "rock-pressure" as a cause of flowing wells of great depth. He claims that such wells tap sections of rock which are, together with the contained water, under enormous compressive strain, and the partial release of pressure in one direction causes the water to rise in

* Senate Doc. 41, 52d Congress, p. 38.



ARTESIAN WELL AT WOONSOCKET, SOUTH DAKOTA.

Depth of well, 750 feet.
Height of stream above ground, 80 feet.
Diameter of well, 7 inches.
Pressure per square inch, 140 pounds.
Temperature of water, 63° F.
Discharge per 24 hours, 11,500,000 gallons.

the tube. This theory is combated by R. L. Jack, Government Geologist, Queensland.*

A phenomenon occasionally met with in deep, non-flowing wells is that of "breathing." Mr. J. T. Willard, of Kansas, has reported an instance of that kind in which close observation was kept of the entrance or exit of air, and the corresponding barometric readings. With a low barometer the well air took an outward direction, and the reverse condition followed increased atmospheric pressure. Mr. R. T. Smith, of Winona, Kan., "utilized such an air-current to blow a whistle which could be heard all over the town, warning the inhabitants of a possible storm." Of course the volume of air moving in such cases is far greater than what would be equal to the cubic contents of the well-tube, and it comes from a storage in porous or cavernous strata.

A "breathing well" near Niagara is described in "The Falls of Niagara" by Spencer, Canada Geol. Sur., 1905: 135.

Attention is called by various writers—notably by Messrs. Todd and Swezey—to the liability of these "breathing wells" to freeze, owing to the sudden inflow of cold winter air from the outside. "The pumps not infrequently froze to the depth of 70 or 80 feet below the surface, and in one case ice had been found in a pump-cylinder 100 feet down, which was about 10 feet above the water."

Other things being equal, the ability of a well to furnish an abundant supply of water will depend upon the water-absorbing qualities of the rock in which the well is bored, and upon the number and extent of the channel-ways that may have formed therein. F. G. Clapp † has pointed out that the hard, compact and close-grained types of slate commonly contain more water than any other formation except sand, gravel, sandstone and limestone. The water is held to some extent in cleavage cracks, but mostly in joints, which traverse the rock in all directions.

* Aust. Asso. Adv. Sci., 1895. † Water Supply Paper No. 223.

He also notes that in limestone water exists in pores and along joint cracks and stratification planes, but mainly in solution channels or cavities which have been formed by the slow solvent action of the waters. "Many of the cavities, but not all of them, have been formed through the enlargement of joints; therefore they center about the intersection of fracture systems. Small solution channels, a few inches in width, and frequently many hundred feet long, can be seen in nearly all limestone districts, but passages of cavern size are found only in certain limestones. The best example in this country is the Mammoth Cave of Kentucky. In this cave some of the passages are 20 to 70 feet high and 50 to 100 feet broad."

In crystalline rocks joint cracks occur as in slate, but water is present as well in what Clapp terms "concentric joints which are approximately parallel to the surface, and contain small quantities of water. They have been formed by alternate expansion and contraction of the upper zone of the rock owing to changes of temperature. These joints are generally only a foot or two apart near the surface, but many feet apart at greater depths."

Contrary to the belief of many people, deep-seated water is not inexhaustible. If the porous layers containing it be extensive, an immediately available supply of large volume, which is the accumulation perhaps of ages, may be counted upon; but should the daily drain be larger than the natural reinforcement, the delivery must surely shrink in quantity, and finally cease.

Van Hise * calculates that the water in the rocks to a depth of 10,000 metres is equal to a sheet covering all the continental areas 69 metres, or 226 feet deep.

M. L. Fuller † estimates that the average per cent of rock occupied by water in the earth's crust is 0.52.

He adds: "The total free water held in the earth's crust

* Data of Geochemistry, paper 22.

† Water Supply Paper No. 160.

would be equivalent to a uniform sheet over the entire surface with a depth of little less than 100 feet (96 feet), which is only about three-sevenths of that estimated by Van Hise. It is recognized that locally, where the sediments are very porous and of considerable thickness, several times the amount of water estimated may exist in unconsolidated deposits, or in the stratified rocks alone. There is a general tendency, however, to overestimate the amount of water in the ground owing to the impression of great volume which a large well often conveys, the fact that a large area is drained being frequently overlooked. The average amount of water present in the earth is probably under, rather than over, the amount estimated.

It is common knowledge that a great volume of water, some sixty-six million U. S. gallons, is drawn daily by the London water department from deep wells in the chalk.*

The serious effect of extending and heavily pumping these deep chalk wells supplying a portion of London is thus pointed out in the *British Medical Journal* for February 28, 1891:

"For every two gallons of water collected within the Lee valley London is withdrawing three from its reservoir in that chalk basin, and this quite apart from the amount every day required by the resident population of the area. The result of such a process can only be a steady, if gradual, exhaustion of water from the chalk, and a progressive lowering of its plane of saturation; and, unfortunately, facts abundantly confirm this calculation, and prove that such a lowering of the deep-water level is proceeding not merely in the valleys of the Colne and Lee, but in the main valley of the Thames itself as well; and this, moreover, to a degree which has already begun to excite the alarm of both agriculturists and manufacturers.

"Springs which were perennial and abundant thirty years ago have now run dry; the level of the water in deep wells has fallen more than 20 feet within less than as many years. Mills are being abandoned for lack of water-power, and rivers which once flowed regularly past ancient mansions, built to

* London Water-supply, Shadwell, p. 48.

command a view of their bank-full streams, are now lost in swallow-holes, or flow only scantily, or for a few weeks in occasional years. In 1821 the water in a well in the east of London stood at Trinity high-water mark—22 feet above the present ordnance datum; in 1851 its average height was 43 feet below; and in 1881 it was 105 feet below ordnance datum, a lowering of 127 feet in sixty years, and indicating a fall in the plane of saturation in the chalk of more than 200 feet in the century. This depletion is not explicable on any theory of a diminished rainfall; for in this district the average of the last twenty years (during which the fall has taken place at an increasing rate) is nearly 2 inches above the average rainfall for the previous thirty years. The cause is to be found wholly and solely in the fact that water has been, and is being, increasingly drawn from the chalk basin in excess of the supply."

Similar lowering of the deep-water table is taking place in this country; notably in Indiana.*

The water-supply of Copenhagen, Denmark, is entirely from deep sources, reached by 5-inch wells bored through the glacial deposits overlying the stratum of chalk to which, or into which, the borings extend. Upon reaching the chalk layer, if it be found covered with coarse material, the well is not pushed to a greater depth, but should the covering layer be of fine grain then extension of the boring is made into the body of the chalk itself. Very numerous trial borings have been sunk throughout the country surrounding Copenhagen whereby complete contour maps have been made showing the undulations of the surface of the chalk deposit, referred to sea-level, and also giving the height at which the deep-seated water will rise, referred to the same datum.

The wells are from 150 to 200 feet deep and are sunk at an expense of about one dollar per foot.

As would be expected, the water is very hard and is ill suited to industrial uses until softened. Such improvement is,

* See paper by Brossman on "Water Supplies of Indiana," read before the Indiana Sanitary and Water Supply Association, Feb. 25, 1910.

however, always a private enterprise, the city undertaking to remove no mineral ingredient beyond iron carbonate, which latter is present in considerable quantities, 4.1 parts per million, or 2.3 parts Fe.

The wells are tapped off into a common suction-main, whence the water is raised some 60 feet to an aerating house, where the soluble iron is oxidized to the insoluble form.

This aeration and oxidation is accomplished by causing the pumps to deliver the water to a series of open troughs of cast-iron, twenty-four in number, each one being 12 feet long, 8 inches deep and 8 inches broad. These troughs are movable at either end so that their level may be adjusted. The water overflows their sides and falls in thin sheets into the collection well, 8 feet below, whence it flows by gravity through a conduit for some fourteen miles to a slow-sand filter plant situated within the city limits.

As the water reaches the filters it is, of course, rusty in appearance from the suspended iron, and the removal of this material is the only function which the filters have to fulfil. The iron remaining in the filtrate corresponds to .14 part per million of the carbonate.

At the time of the writer's visit it was proposed to increase the time between cleanings by passing the water rapidly through small "roughing" filters of gravel and small stones before allowing it to flow upon the filter proper.

No difficulty with crenothrix has been experienced. The filtered water is pumped directly into the distribution mains.

Upon examining the contour maps already referred to, it is noticed that "cavities" in the chalk have been formed at the location of the several well stations and it is also observed that "cavities" in the level of the water horizon have been formed about the points of withdrawal, although the authorities state that careful measurements have shown that no lowering of the general water-level has resulted from the operation of the pumps.

The "deep" supply for the town of Asbury Park, N. J., is quite typical of the low-lying waters of that coast, and

is, moreover, an instance of the successful treatment of a water so highly ferruginous as to be unusable in the raw state.

The wells are ten inches in diameter and a little over one thousand feet deep and furnish a water containing 9.12 parts or iron per million. An " air-lift " is used to raise the water, which reaches the surface very red and roilly from suspended iron. After removal of this by simple filtration through sand an excellent water is obtained, clear and iron-free. The air is forced in through a one-inch pipe, at a depth of about two hundred feet and under a pressure of ninety to one hundred pounds. No clogging of the piping has been experienced.

It is right to say here that although in cases like that of Asbury Park, where oxidation of contained iron is demanded, the air-lift is suited to the existing conditions, yet the fact should always be considered that such a device for the purpose of simply raising water is of very doubtful economy, except where the lift is a small one.*

Deep water must not be expected in every locality. There is a widespread notion that every deep boring is sure to strike water in goodly quantity, if carried to sufficient depth, irrespective of any surface conditions whatever. The writer has been called to pass judgment upon the advisability of trying for an artesian supply for a settlement on the top of a mountain some three thousand feet high, and that, too, a mountain of erosion, with horizontal strata. Shallow borings, of only thirty to forty feet in depth, had furnished a limited quantity of water in the same general locality, and hence the proposition to increase the supply by the means above stated. The water obtained from the shallow wells was, of course, derived from the very local rainfall of the mountain-top, and was no indication whatever of a further deep supply, although the parties interested were of the opinion that water could be induced to run up-hill, owing to some occult " artesian " conditions.

* See Engineering News, April 22, 1897.

Water from deep sources has, commonly, characteristics of its own, distinguishing it from the ground-water of the neighborhood. One of the most easily recognized of these is high temperature. Albertus Magnus was the first to hold that low-lying waters are warmed by the native internal heat of the earth.

Aristotle believed the high temperature of such water to be due to solar heat which penetrated the crust of the earth and accumulated in the interior as at the focus of a lens.

Instances of the gradual increase in temperature with depth of boring have already been given in data on page 425.

Another peculiarity of deep water is the small quantity of dissolved oxygen it usually contains. This is by no means due to the pressure to which it may be subjected, for increase of pressure favors the solution of gases, but is rather owing to the abundant opportunity for removal of oxygen by contact with oxidizable material during the long underground journey of the water from its point of collection.

The water of the Grenelle well at Paris, which flows from a depth of 548 metres (about 1780 feet), contains no dissolved oxygen whatever.

In point of composition the waters of deep wells are almost always highly mineralized, as would be expected in consideration of the items of long time, long distance of flow, high pressure, and elevated temperature. Sometimes the materials contained render the water unfit for use, even for boiler purposes.

E. C. Carter, chief engineer of the Chicago and Northwestern R.R., states that waters on the line in South Dakota from very deep sources, are so alkaline as to cause foaming. They are soft and very hot (130° F.); so hot that the injectors will not deliver into boilers readily because the vapor breaks the suction vacuum. Railroad tanks which receive frequent renewals from these waters do not lose heat fast enough to keep the water cool.

Although manifestly foreign to the present writing, it may be interesting to insert here the analysis of water from " Old

Faithful" Geyser, which may be taken as typical of such deep waters from the Yellowstone Park.*

NH_4Cl	trace	
LiCl	34	per million
NaCl	639.3	"
KCl	47.8	"
CsCl	trace	
RbCl	trace	
Na_2SO_4	27	"
KBr	5.1	"
$Na_2B_4O_7$	21.3	"
$NaAsO_2$	2.7	"
Na_2CO_3	208.8	"
Na_2SiO_3	27.9	"
$MgCO_3$	2.1	"
$CaCO_3$	3.8	"
$FeCO_3$	trace	
$MnCO_3$	trace	
Al_2O_3	1.7	"
SiO_2	369.1	"
H_2S	0.2	"
	1390.8	per million

Mr. Kennish furnishes the following analysis of the water from the Ponce de Leon well already spoken. of The water on issuing from the well has a strong smell of sulphuretted hydrogen (a quality also observed in the water of the Matanzas sea-spring), but all odor leaves it after standing a short time.

Suspended matter	1.6	per million
Silica	28.0	"
Alumina	1.2	"
Sodium chloride	1957.7	"
Potassium chloride	47.5	"
Magnesium chloride	353.4	"

* Gooch and Whitfield, Bul. 47, U. S. Geol. Sur.

Calcium sulphate	470.9 per million
Strontium sulphate	18.6 "
Magnesium sulphate	none
Calcium bicarbonate	149.9 "
Magnesium bicarbonate	162.1 "
	3190.9 per million

Deep waters are not always highly mineralized, however. Note the following:

ANALYTICAL DATA FROM TWO DEEP WELLS OF NORTH CAROLINA.*

(Note the Difference in Hardness)

	Lexington.	Morganton.
Odor	none	none
Color	12.5	12.5
Turbidity	2.6	1.4
Sediment	none	none
Total solids	350.	44.
Alkalinity	76.50	26.
Temporary hardness	76.50	26.
Permanent hardness	171.	17.
Total hardness	247.50	43.
Incrustants	171.	17.
Iron	.15	trace
Phosphates	trace	trace
Chlorine	12.	6.
Nitrates	4.25	.32
Nitrites	trace	none
Ammonia, free	.01	.041
Ammonia, albuminoid	.03	.055

Some years ago a small sample of brown water was sent to this laboratory by the gas company of Mobile, Ala. It came from an artesian well 600 feet deep, bored near the Gulf coast. A very simple and partial examination was made of it to determine its fitness for boiler use. It was decidedly alkaline from the presence of sodium carbonate, contained considerable salt, and in color was of a dark coffee-brown. It is to be

* Bul. N. C. Board of Health, April, 1907.

regretted that circumstances did not favor a complete analysis of so interesting and unusual an artesian water. However, the gap has been filled by Professor Reuben Haines, who sub-

ONE OF THE GROUP OF ARTESIAN WELLS SUPPLYING THE CITY OF JACKSONVILLE, FLORIDA.
The water rises 10 feet above the surface of the ground.

sequently reported a "remarkable artesian-well water" from southern Alabama.* The description of the water, and the depth of the well (685 feet), combined with the location, led

* J. Fk. Inst., January, 1894.

to the conviction that the water was practically the same as the one previously examined by the writer.

The analysis and comments are best given in Professor Haines' own words:

"Color (observed in tube two feet long)—very dark coffee-brown.

"Odor (heated to nearly 100° C.)—unpleasant, odor of damp rotten wood.

"Taste (warm)—disagreeable, stale, brackish alkaline with organic flavor.

"Transparency—almost clear, a small amount of whitish sediment.

Free ammonia	6.900	per million
Albuminoid ammonia	0.740	"
Oxygen consumed (Kubel)	10.892	"
Nitrogen in nitrates	0.40	"
Chlorine	998.0	"
Total solid residue (dried at 120° C.)	2060.0	"

"The mineral ingredients existed in the following combinations:

Potassium sulphate	2.2	per million
Potassium chloride	44.0	"
Sodium chloride	1611.9	"
Sodium carbonate	293.3	"
Calcium carbonate	26.8	"
Magnesium carbonate	13.4	"
Silica, iron oxide, and alumina	8.5	"
	2000.1	per million

"The more remarkable features of this artesian-well water which are here to be noted are the very high color, approximating that of water from pools in bogs and swamps, and the enormous amounts of ammonia and of organic matter. Deep-wells and artesian waters are usually colorless and particularly

free from organic matter, on account of the vast amount of filtration to which they are generally subjected. It does not seem probable that so excessive an amount of ammonia as occurs in the Alabama well can be referred to decomposition of the vegetable substance alone, but that a portion of it, at least, must be caused by decomposition of the organic remains of fish and other marine animals, which have been, perhaps, partially preserved from decay through the antiseptic properties of peat. A quantity of bones and shells mingled with sand is stated to have been thrown up by this well.

"The excessive amount of sodium chloride in this well-water may be attributed to the probable existence of saliferous beds somewhere in the vicinity. From the results of analysis it is manifest that the water has no direct connection with the sea, for its mineral composition is totally unlike that of sea-water. The pressure of the water at the mouth of the well is of itself sufficient evidence that the water has an altogether different origin."

Water of high color and of general swampy character is to be found in the deep wells in the vicinity of New Orleans, and is also reported in Colorado.* Only one explanation is apparent for all these cases, and that is that the water coming from its distant gathering-ground is constrained, for a portion of its underground course, to pass through deep-lying deposits rich in organic remains.

As to what kind of rocks yield hard water and what kind furnish soft, we have but to consider the chemical and physical structure of the rock in question, and then, from the solubility data, a very fair judgment can be arrived at. Professor Carter has summed up this question very aptly.† He says.

"Water that passes through calcareous or magnesium rocks of great thickness will probably be hard, while water that passes through rocks composed of silica, alumina, iron, potash, or soda will probably be soft. The great deposits of

* J. Am. Water-works Asso., 1897, p. 137.

† J. Fk. Inst., September, 1893.

limestone, marble, gypsum, and other calcareous rocks, as well as the magnesian rocks, such as dolomite, chlorite, and talcose schists, would then yield hard water. The granites, gneisses, and many sandstones and slates would furnish soft water. This, in the main, is true, although there are some exceptions which local conditions modify. Some sandstones will yield soft water, while other sandstones furnish hard water; it depends mainly upon the cement which binds the grains together. If the cementing material be carbonate of lime or sulphate of lime, the water will probably be hard, especially if the well be of great depth and the water be long in contact with the rocks. If, on the other hand, the cementing material be feldspar, such as orthoclase or albite (not labradorite), or even gelatinous silica, the water will probably be soft.

"Water which flows through calcareous channels is hard, while that which flows through silicious rocks is soft."

As has been shown, deep water may at times be too highly mineralized, or even too "peaty," for potable use, but such impurity is not the only form that may be present on occasion.

Even a deep well, especially if not a true flowing artesian, is not always exempt from local infiltrations of contaminating character. The writer condemned a deep-well water from Erie, Pa., upon the following analysis:

Free ammonia	2.025
Albuminoid ammonia	none
Chlorine	69
Nitrogen as nitrates	.025
Nitrogen as nitrites	none
"Required oxygen"	.85
Total solids	487
Phosphates	strong traces

The well had been bored within city limits, through a friable rock, and within 75 feet of the nearest privy-vault.

Adverse report was also made upon another well, which had been very carefully bored through rock (shale) for 200

feet. Within 50 feet of the well was a large privy-vault. Sixty-five pounds of salt, dissolved in three barrels of water, were thrown into the vault, and the water of the well was watched for increased chlorine, with the following results:

Before "salting"	58	parts chlorine per million
After 15 hours' pumping	64.25	" " "
" 36 "	64.37	" " "

Careful lining of the well with iron pipe will not with certainty safeguard the water from contamination. No better illustration of this truth can be had than the circumstances attending the typhoid disaster at the school already given, where a broken sewer-drain permitted pollution to run down the annular space between the rock wall and the outer side of the pipe. From the bottom of the well so infected the water was pumped for drinking purposes.

The mere fact that the well is deep is commonly considered to insure safety, and fortunately the trust is usually not misplaced, but much depends upon the character of the material into which the well is sunk. Chalk or limestone wells are sometimes unreliable because of the highly-fissured formations likely to be encountered, and again there are found, as stated above, deep-well waters polluted by surface material when the drilling has been done in friable material, such as Hudson River shale.

Waters from deep sources are not to be rated as "uniformly sterile." Leaving out of consideration such instances as wells which permit the direct entrance of surface drainage, there are yet many deep waters showing abundance of bacterial life; but, fortunately, the chances of encountering therein germs of objectionable character are reduced to a minimum. Prof. Sedgwick has reported his findings upon this question:

"From our results we are forced to the conclusion that ground-waters, even the waters of deep wells, may not be by any means as free from bacteria as has been hitherto supposed.

"It is plain that water absolutely free from bacteria is not ordinarily obtained from even deep wells, and that many deep

wells contain as numerous bacteria as are found in many surface-waters."

The bacteria present in these waters are, however, "remarkable not only for slow growth, but also for the absence of liquefying colonies, and, in many cases, for the abundance of chromogenic varieties. These facts are especially important as indicating the total absence of contamination by ordinary surface-water, and, as far as they go, they strengthen the confidence with which well-protected ground-waters may be regarded as sources of public water-supplies." *

Kellerman and Whittaker † report finding *B. Coli* in 1 c.c. samples of water from 6 out of 13 rock-drilled wells examined. It should be borne in mind that if deep wells become by chance polluted, the probable absence of competing organisms would give those of pathogenic character a better opportunity to become dangerous.

Before concluding this chapter on deep-seated water the writer begs to introduce a somewhat extraneous matter, that can claim attention only because of its unusual character.

Kephalonia, the largest of the Ionian Islands, lies off the west coast of Greece and is some thirty miles long by twenty miles broad. Near its principal town of Argostoli are mills equipped with undershot wheels which are driven by sea-water flowing landward from the coast.

In the words of Baedeker, "The mills are driven by a current of sea-water which flows into the land for about fifty yards finally disappearing amid clefts and fissures in the limestone rock."

The illustration shown herewith is of the "Old Mill" erected in 1835, and shows the water flowing in the tail-race towards the point of its mysterious disappearance, which is some ten feet below the level of the sea. The question is, Where does the water go?

During the British occupancy of the island, pitch, petroleum and other easily noticeable substances were poured into these

* Sedgwick, Rep. Mass. Board of Health, 1894, p. 443.

† U. S. Dept. Agri. Bul. 154.

" clefts and fissures " and a strict watch of the surrounding sea failed to detect their reappearance.

Is it not possible that the water which sinks into the rocks of Kephalonia comes to the surface again in the form of steam at Stromboli, Vesuvius or other volcanic vents?

Crosby suggests another explanation, namely, that an extinct

SEA-MILL, KEPHALONIA, GREECE.

volcanic vent at Kephalonia receives the water and passes it to another similar arm of a mighty U. The water after reaching the lowest level becomes heated and then rises in the second arm of the U. Under such conditions constant flow in one direction would be established and the discharge might be made at some distant point of the sea bottom.

CHAPTER X

QUANTITY OF PER CAPITA DAILY SUPPLY

THE following table is from a paper by Nicholas S. Hill, Jr.,* giving data as to

PER CAPITA WATER CONSUMPTION IN UNMETERED CITIES OF THE UNITED STATES

	Daily Consumption per Capita. (U. S. Gallons.)
Connecticut:	
Bridgeport	200
Hartford	68
Meriden	100
New Haven	150
New London	155
Stamford	150
Waterbury	91
New York:	
Albany	220
Auburn	182
Binghamton	140
Brooklyn	91
Buffalo	309
Elmira	132
Ithaca	133
Kingston	266
Newburgh	144
New York (Manhattan)	104
Oswego	196
Poughkeepsie	93
Rochester	94
Schenectady	123
Syracuse	120
Troy	271
Yonkers	96
New Jersey:	
Atlantic City	245
Camden	125
Elizabeth	164
Jersey City	156
Newark	102

* J. Am. Water-works Assoc., March, 1915.

	Daily Consumption per Capita. (U. S. Gallons.)
New Jersey:	
Passaic	72
Plainfield	150
Trenton	191
Pennsylvania:	
Allegheny	251
Altoona	94
Bradford	117
Erie	153
Johnstown	160
Lancaster	120
Norristown	80
Philadelphia	178
Pittsburgh	221
Reading	138
York	66
Average	161

PER CAPITA CONSUMPTION OF WATER IN CITIES HAVING A LARGE PERCENTAGE OF METERED SERVICES

	Per Cent Metered Services.	Daily Consumption per Capita. (U. S. Gallons.)
Anniston, Alabama	76	128
Atlanta, Georgia	100	65
Bayonne, New Jersey	100	95
Bessemer, Alabama	70	46
Brockton, Massachusetts	90	38
Cleveland, Ohio	94	100
Consolidated Water Company	85	71
Covington, Kentucky	100	51
Geneva, New York	91	35
Harrisburg, Pennsylvania	83	122
Hartford, Connecticut	98	68
Lexington, Kentucky	98	58
Lincoln, Nebraska	100	40
Milwaukee, Wisconsin	99	105
Montclair, New Jersey	100	66
Newton, New Jersey	86	58
New York Inter-Urban Water Company	95	78
Passaic, New Jersey	54	72
Providence, Rhode Island	90	68
Rochester and Lake Ontario Water Company	100	94
Utica, New York	98	59
Yonkers, New York	100	96
Average		73

PER CAPITA CONSUMPTION IN THIRTY-SIX ENGLISH PROVINCIAL CITIES

(London County Council Report, 1897)

	Average Daily Supply, U. S. Gallons, per Capita.
Barrow	42
Birkenhead	31
Birmingham	28
Bolton	26
Brighton	43
Bradford	31
Burnley	26
Bury	29
Cardiff	29
Coventry	28
Croydon	35
Derby	27
Gloucester	21
Halifax	24
Huddersfield	30
Hull	49
Ipswich	21
Leeds	43
Leicester	22
Lincoln	28
Liverpool	34
Manchester	40
Middlesborough	61
Newport	27
Northampton	23
Nottingham	24
Oxford	30
Plymouth	59
Reading	42
St. Helens	49
Salford	26
Sheffield	21
Southampton	45
Swansea	35
Wigan	20
Worcester	43
Average	33

PER CAPITA CONSUMPTION IN GERMAN CITIES

(After Brackett)

Place.	Population.	Daily Consumption, U. S. Gals.	Place.	Population.	Daily Consumption, U. S. Gals.
Altona	156,500	26.07	Hanover	189,976	18.40
Barmen	118,500	33.59	Halle	120,000	21.94
Basel	74,500	34.78	Karlsruhe	74,200	28.14
Berlin	1,606,424	16.37	Kiel	72,000	20.18
Bonn	52,000	24.94	Königsberg	162,000	16.87
Breslau	335,000	21.71	Magdeburg	198,000	25.24
Chemnitz	139,374	11.50	Munich	298,000	34.00
Cologne	255,000	45.22	Nuremberg	145,000	17.41
Crefeld	105,712	18.52	Posen	70,000	13.33
Danzig	107,085	26.70	Stettin	118,000	31.54
Dresden	280,200	21.54	Stuttgart	139,200	21.34
Düsseldorf	155,900	22.10	Wiesbaden	66,000	20.74
Elberfeld	137,000	29.92	Würzburg	61,032	35.50
Frankfort	186,000	36.26	Zurich	96,650	56.71
Freiburg, B.	48,200	41.46			
Hamburg	583,700	58.00	Average	.....	27.69

The nine large conduits of Rome at the time of Nero delivered 173,000,000 gallons daily. Afterwards the increased supply furnished 312,000,000 gallons daily, or over 300 gallons per capita per day.*

Upon glancing over such data as have been given for cities of the United States, and bearing in mind how often the water furnished our towns is inferior in character, one is impressed with the thought that we Americans are often more concerned about the quantity of the supply than about its quality.

There is no question but that our allowance is unreasonably large. Fifty gallons is considered a generous amount per individual in Europe, but it would be deemed quite a small quantity here in America.

If we had but an increased cleanliness to show for our great use of water, there would be a measure of compensation for the additional cost, but the writer confesses to an inability

* Senate Doc. 41, 52d Congress, part 1, p. 431. For estimates of Forbes and Clemens Herschel, see p. 10.

to detect wherein our American cities are superior to those of Europe in this particular.

The question of what is a suitable quantity of water to allow for daily consumption per capita is a very vexed one and great variety of opinion is on record. "Water should be as free as air" is insisted upon by some, while their opponents are strong in the belief that an individual consumer has no more right to unnecessarily increase the public charge for water than he has to ask his neighbor to help pay for his waste of illuminating gas.

"Plenty of water helps to flush the sewers" is advanced by others as an argument for a large per capita allowance; but whoever has seen the small volume of sewage that commonly flows along the bottom of a sewer can well understand how slight a chance for efficient flushing is furnished by any reasonable increase of per capita water allowance.

It would seem that an allotment of 100 gallons per capita per day should be considered liberal and yet, in view of the wasteful habits that our water consumers have acquired, engineers are forced to be somewhat cautious in designing for a supply based upon that reasonable figure.

In estimating the future needs of the city of Baltimore those in charge of the new works concluded it safer to assume that the following per capita daily supply would be required:

1915	130 gallons
1920	135 "
1930	145 "
1940	150 "

As cities grow in population and as the mileage of sewers and the introduction of plumbing is extended the amount of water used and wasted per individual inhabitant also increases.

Each use of an ordinary bath-tub requires about 20 gallons of water and every emptying of a toilet tank calls for 4 gallons in addition. Possession of sewer facilities naturally increases plumbing conveniences with their inevitable waste of water. The enlargement of the per capita supply occasioned by the

introduction of public water and a system of sewers is well shown by the following data published by the Mass. Board of Health Report, 1900, page 607:

"Table showing the increase in the consumption of water per person with the age of the works. (Average of twenty-four cities and towns.)

Year After Water Was Introduced.	Average Consumption per Person per Day.	Year After Water Was Introduced.	Average Consumption per Person per Day.
First	23	Sixth	37
Second	28	Seventh	39
Third	30	Eighth	40
Fourth	32	Ninth	42
Fifth	36	Tenth	43

"This table shows an increase, in ten years, of nearly 100 per cent.

"Average consumption of water in three cities before and after the introduction of a fairly complete system of sewers."

City.	Years Previous to Introduction of Sewers.							Years Subsequent to Introduction of Sewers.								
	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	9
Marlborough	13	17	20	21	24	24	25	30	30	35	34	37	37	38	38	36
Newton	28	31	33	33	31	36	40	50	52	60	65	63	60	57	63	62
Waltham	37	36	39	33	31	32	33	47	53	61	59	71	70	76	88	90

Analysis of the sundry items included under the general head of "Water for Public Purposes": *

	U. S. Gallons per Capita per Day.
Public buildings, schools, and hospitals	2.30
Street-sprinkling	1.00
Flushing sewers and public urinals	.10
Ornamental and drinking fountains	.25
Fires	.10
Total for public purposes	3.75

* J. N. E. Water-works Assoc., xi. 71.

"Probably 4 or 5 gallons per capita should cover all requirements for public purposes."

The useless waste of water in our cities is something enormous. In Chicago, Cleveland, Philadelphia, and Detroit the probable waste has been estimated at about 50 per cent, while in Buffalo the enormous figure of 70 per cent was given by the city engineer.

That the great bulk of this waste could be saved by meter measurement is an already demonstrated fact, and the fixing of a minimum daily allowance of water, for which the consumer would have to pay, whether he used it or not, would remove the objections that might be raised to meters upon sanitary grounds. The author has corresponded with city health officers in various parts of the country, with a view of determining what, if any, is the effect of the meter system upon public health, arising from an attempt on the part of the poorer classes to economize in the use of water. The reply from Providence, R. I., is quite typical: "I do not find that it diminishes the proper use of water in the slightest degree. Its only tendency is to diminish waste. There is in my opinion no objection, from a sanitary point of view, to the use of meters."

In Providence, R. I., the minimum charge was $10 per family per year, which entitled them to 91.32 gallons per family per day, or at five persons per family to 18.26 gallons per capita daily.

An analysis of the water accounts of 2553 families who paid the minimum rate, but who were "of a good class" showed the following results:

167	families	used	less than	6.15	gallons	per capita	daily.
237	"	"	"	8.20	"	"	"
361	"	"	"	10.25	"	"	"
445	"	"	"	12.30	"	"	"
446	"	"	"	14.35	"	"	"
462	"	"	"	16.40	"	"	"
435	"	"	"	18.27	"	"	"

Hence the bulk of these people did not use all for which they were paying.*

It is often assumed that the water required for fire service represents a large fraction of that charged to per capita consumption, and this may readily be true for small places; but as cities grow in size the draft made by the fire engines becomes progressively smaller per individual citizen. Placing 250 gallons per minute as the water needed for a fire stream (the hydrant pressure being say 75 pounds) and allowing ten such streams for a fire, the sum total of water thrown does not represent a serious addition of cost to each taxpayer in a large community.

In this connection it is interesting to note that during the great fire at Baltimore when over fifty engines were at work, and when further loss of water occurred through the breaking of thousands of service pipes, the flow of water exceeded the average daily consumption by only 82 per cent.†

Discussing the question of fire service, Mr. Nicholas S. Hill, Jr. says:‡

"When fire service is furnished directly from the mains, service pressures of not less than 70 to 75 pounds at the hydrant under conditions of maximum draft should be maintained in the congested value districts, although 50 to 60 pounds minimum will usually suffice for residential sections. With these pressures, fire streams throwing from 200 to 250 gallons per minute through $1\frac{1}{8}$-inch smooth nozzles attached to 200 feet of $2\frac{1}{2}$-inch ordinary, best quality, rubber-lined hose may be obtained.

"Where fire engines are used, a service pressure of 30 pounds minimum on the mains will usually be ample in residential sections, as this pressure will insure the delivery of water to the fourth story of an ordinary building."

"Various opinions have been expressed as to the quantity of water needed daily for a soldier on the march. In France

* J. N. E. Water-works Assoc., xviii. 1.

† Engineering Record, June, 1904, paper 732.

‡ J. Am. Water-works Assoc., March, 1915.

it is generally estimated that each man should be provided while in camp with a daily supply of 30 litres (8 gallons), with an extra allowance of 5 litres for mounted men. The German authorities place the daily requirements at 50 litres ($13\frac{1}{4}$ gallons), while in Austria 40 litres ($10\frac{1}{2}$ gallons) are held to be necessary. In Great Britain the official barrack allowance is 24 U. S. gallons per man or horse, and 12 gallons for each child. Naturally, an army in the field is in a different position from a soldier in barracks." *

East Indian troops employed during the war in Europe (1915) are found to require much water. They bathe before each time of prayer, and, as they pray five times daily, the water used while in the hospital amounts to 84 U. S. gallons per capita.†

* "Water and Water Engineering."
† J. Roy. San. Inst., 36: 409.

CHAPTER XI

ACTION OF WATER UPON METALS: TANKS, PIPES, CONDUITS, BOILERS, ETC.

Lead. Many waters, especially those that are soft, and particularly water that has been distilled, will act on the common metals with varying degrees of intensity, lead, zinc and iron being those usually attacked. Because of the serious effect upon health resulting from the presence of lead in drinking water that metal deserves particular consideration; all the more so as lead is a cumulative poison.

The Massachusetts State Board of Health enumerates the symptoms of lead poisoning as some or all of the following: Anæmia, constipation, indigestion, loss of appetite, thirst, metallic taste, abdominal pain, colic, "drop-wrist," blue line at margin of gums, lead in the urine.*

Dr. Hunter, describing the effects of the epidemic at Pudsey, says: "Anæmia and debility were the most common symptoms. Patients nearly always complained that they felt as if they would sink down from weakness, and that the least exertion would make them sweat freely. The majority had the blue gum line so characteristic of lead poisoning. Colic was a common symptom. Paralysis was not common, but there were five or six cases of almost general paralysis and in these cases 'drop-wrist' was included. The amount of lead found in the waters producing these effects varied from .01 to 1 grain or more per imperial gallon.† (.143 to 14.3 per million.)"

There is some difference of opinion among the authorities as to the amounts of contained lead required to condemn a water, but all are agreed that even small quantities should be

* Report of Mass. State Board Health, 1898, xxxiii.

† Thresh, "Examination of Water," p. 88.

narrowly watched. Thus, the Massachusetts reports note that one-half part per million has caused serious injury.* Haines holds that .1 grain per U. S. gallon (1.71 per million) should cause a water to be rejected.†

Whitelegge believes that "No water should be used for drinking which contains more that one part of lead per million, and any trace, however minute, indicates danger." ‡

To quote Dr. Summerville in his paper in "*Water*": "Lead to the extent of .25 part per million is sufficient to condemn a potable water."

That sundry public waters contain enough lead to prevent their acceptance by at least some of the standards laid down is shown by the fact that a few years ago it was reported that sixty-three cities of Massachusetts possessed public water supplies which contained lead in amounts varying from 85.46 to .032 per million. In four of these cities where lead poisoning was pronounced the average amount of the metal present during ordinary day time use was one part or over per million. Occasional instances of "plumbism" were noticed in other towns and doubtless other mild or unrecognized cases occurred elsewhere.§

In the 31st annual report of the London local government Board,‖ peaty, moorland waters are shown to be especially plumbo-solvent, to a degree chiefly governed by the amount of acidity present, and experiments show that such acidity is due, at least in part, to acid-form bacteria residing in the peat.

That all peaty waters act on lead must not be inferred, as some very brown ones, notably from New Jersey, are without such action. Certain organic matters even serve as protective agents.

The London report already quoted calls attention to the fact that moorland streams are highest in acidity during wet weather because of drainage from peaty surface sources and

* Mass. State Board of Health, 1898, xxxii.

† J. Fk. Inst., Nov., 1890.

‡ Hygiene and Public Health.

§ Mass. State Board of Health, 1898, page 543.

‖ 1901-02 Supplement on Lead Poisoning and Water Supply, vol. 2, page 426.

less so during periods of no rain on account of their supply at such seasons coming from the flow of springs.

In this connection it may be noted that H. W. Clark observed that carbonic acid in a soft water was the main factor that caused lead to be taken into solution by the waters from Massachusetts.*

It is by no means new to distinguish between the "solution" of lead and that "erosion" of the metal which some waters exercise whereby insoluble lead salts are formed with appreciable increase in the turbidity of the water.

Such classification of the action upon lead has been developed with great care in the report of the London Local Government Board.

For our purposes it will suffice to note that "erosion" does not occur in the absence of oxygen, and we are also to remember that from the sanitarian's point of view "erosion" may be fully as objectionable as "solution" if no opportunity for clarification be furnished. In fact, the former may readily be the greater evil of the two, because of its involving the possibility of the ingestion of large quantities of lead salts held in suspension.

In a general way it may be said that soft waters attack lead and hard waters protect it, but this rule is not without numerous exceptions. Waters of acid reaction take lead into solution, while those of neutral or alkaline character hold the basic hydroxide or basic carbonate in suspension. As the latter class of waters often attack lead quite vigorously, the quantity of lead actually imbibed with an unfiltered water of this type may be considerably larger than in the case of a water where the lead is in solution.

Instances are on record of lead pipes having been in use during many years without having been acted upon by the water passing through them. Thus Fischer cites a case where the pipes had served over 200 years without action. An interior incrustation on a lead pipe which had been in use for conveying water at Andernach during a period of 300 years was found to consist of:

* Engineering News, Dec. 1, 1904.

PbO	73.962
BiO_3	0.453
CdO	0.120
CuO	0.323
Fe_2O_3	1.552
Al_2O_3	1.035
CaO	1.095
MgO	0.283
P_2O_5	8.446
CO_2	1.110
Cl	1.254
Organic matter	0.388
Si_2O and clay	4.399
Water	6.141
	100.561

The organic matter was said to have been caused by eels which had been formerly employed to clear the pipe from material that had clogged it.*

A marked difference commonly exists between the action of the same water upon new, bright lead and upon that which is dull from exposure, i.e., " old lead."

Thus the writer found the following amounts of the metal (partly dissolved and partly suspended) in city rain-water which had been stored three and a half months in contact with lead surfaces of the above description.

Old lead	3.65 parts per million
New lead	58.10 " "

The important lesson derived from this is that lead-lined tanks for storage of rain-water, such as are often seen in the country, may grossly contaminate the water, especially while new. If lead cisterns or storage-tanks be deemed necessary they should always be carefully painted on the inside with a good carbon (non-metallic) paint, and should be frequently inspected.

* J. Chem. Soc., xxxviii, 198.

As has been mentioned before, there is danger in having a suction-pipe of unprotected lead leading to the bottom of a domestic well or a rain-water cistern.

As already said, all waters do not act upon lead, and some very quickly form upon the metal a permanent protective coating. Carbonate of calcium is efficient in protecting lead from attack.

Crookes, Odling, and Tidy have shown the great protecting power of calcium silicate, and their belief is that water becomes lead-proof when the contained silica amounts to about 7 parts per million.*

Where circumstances permit, an excellent method of checking the lead-dissolving powers of a soft water intended for city supply is to admit to the reservoir or mains a suitable quantity of temporarily hard spring-water. The amount of such spring-water required would depend upon its composition, but would be usually very small.

Another remedy is to allow the entering water to flow over a bed of marble or limestone, or else add to it a very fine suspension of chalk, as is done at Sheffield, England.

The above procedure is available for treatment of peaty, acid waters of the moorlands; but when the plumbo-solvency is due to the carbon dioxide so frequently carried by ground waters, greater success will follow the use of simple aeration by means of a spray nozzle, as was demonstrated at Lowell, Mass. The report says: †

"The carbonic acid can be reduced from 45 parts per million in the raw water to about 3.3 parts per million in the aerated water, and with this reduction the effect of the water on lead pipes is so far lessened as to tender the supply safe.

"The removal of carbonic acid by aeration has a great advantage over the lime treatment in that it does not increase the hardness, and further, as indicated by the tests, aeration is more effective than the lime treatment in reducing the cor-

* J. Soc. Chem. Ind., vii. 15.

† Report on "Improvement of the Water Supply of the City of Lowell, Mass.," made in June, 1914, by F. A. Barbour, James H. Carmichael and Robert J. Thomas.

rosive action when an equal amount of carbonic acid is left in the treated water. This result is not what might be expected, because by aeration the dissolved oxygen, which has generally been considered a contributory factor in corrosion, is increased, but the experiments clearly indicate that, with an equal content of carbonic acid, the aerated water takes up less than the lime-treated water."

That carbon dioxide in water will cause it to dissolve lead is easily shown by the routine experiment of blowing the breath through a sample of water, immersing therein a piece of the bright metal for a few hours and then testing for lead as usual.

Zinc. Piping water in tubes of galvanized iron is common, and as zinc is often as easily attacked as lead it is pertinent to ask if it be equally dangerous. So far as our present experience can guide us toward a correct answer to this question, the reply must be a negative one and the following opinions are presented in support of such contention:

In the Journal of the German Society of Gas and Water Engineers of 1887, H. Bante collected statistics to show "that the use of galvanized pipes should be in no way detrimental to health."

Similar views are entertained by V. Ehumann, director of the Water Supply of Würtemburg.*

According to Thresh † "There is no doubt that waters containing traces of zinc are used continuously for long periods without causing any obvious ill effects. The water-supply to a small hospital with which I was connected for some years always contained a trace of zinc, probably never more than half a grain of the carbonate per imperial gallon (7.1 parts per million), but I never observed any indications of its being deleterious, although such effects were looked for."

On the other hand D. H. Stacks ‡ reports a case of widespread illness in a town which was caused by conveying artesian

* J. Fk. Inst., Nov., 1890.

† "Examination of Waters and Water Supplies," p. 85.

‡ Engineering News, April 3, 1913.

water, impregnated with hydrogen sulphide, through pipes of galvanized iron. The sulphide of zinc added to the water amounted to over thirty parts per million, and produced symptoms of cramps, fainting spells and nausea.

In the Massachusetts Board of Health report for 1900, page 495, the following table is given showing amounts of zinc in sundry public supplies, the metal having been dissolved from pipes of galvanized iron or brass during ordinary use. The results are averages and are in parts per million:

West Berlin	18.46	Lowell	0.33
Milbury	3.08	Webster	0.28
Newton	1.25	Sheffield	8.65
Marblehead	0.85	Palmer	2.90
Grafton	0.73	Beverly	2.71
Wellesley	0.68	Fall River	0.07
Fairhaven	0.52		

The first of the above, West Berlin, drew its water through four thousand feet of galvanized iron pipes. The quantity of metal dissolved therefrom was certainly large, but appears to have produced no evil results. "As far as is known the amount of zinc present in these waters as used is not sufficient to have any effect upon the health of the consumers of the water."

"The Board has investigated the question of the presence of zinc in drinking-water supplies where galvanized iron pipes are used and, except in case of the use of some ground-waters, containing very large amounts of free carbonic acid, which dissolves zinc and many other metals very freely, the amount of zinc found in ordinary water supplies, where galvanized pipes are used, is not sufficient, in the opinion of the Board, to give anxiety." (Massachusetts Board of Health, 1902, xliii.)

In a private letter of more recent date the president of the above-mentioned board said: "If there has been any harmful effects of the presence of zinc in the public drinking-water of the State that fact would have undoubtedly been brought to our attention. No statement to this effect has been made,

nor has there seemed to this board reason for suspecting serious danger from this source."

As an instance of long-continued use of a water containing much zinc, the case of Brisbane, Queensland, should be quoted. In that city rain-water tanks built of galvanized iron are found in all the houses. The water, which is in common use, contains about 17.1 parts per million of zinc, yet no harmful effects have been observed.*

Unlike lead, zinc is not a cumulative poison, therefore the presence of the metal in very small quantities is not so objectionable. There are not a few authorities who claim that zinc poisoning, through the use of water, has not been proven, although P. F. Frankland reports such a case arising from the use of water from a shallow, sewage-polluted well. Waters from such wells were long ago shown to act quickly upon zinc.†

In the *Analyst*, iv. 51, is a report of an analysis of the spring-water supply of Tuttendorf, Germany. The zinc present corresponds to .007 part of the oxide per million; the water has been in use a century.

The great insolubility of those compounds of zinc commonly formed by the action of water upon the metal constitutes a material safeguard.

The writer has been unable to trace any evil effects due to the presence of zinc in drinking water, even when the quantity rose as high as 23 parts per million in a water which is in constant use. It might be well to add, that in the particular case just cited the zinc was derived from a long stretch of galvanized iron pipes and the amount of the metal present was subject to great and frequent fluctuations for reasons that were not apparent.

Dr. Boardman believed that oxide of zinc, as it occurs in drinking-water, is absolutely harmless. He said the same of the carbonate. As to salts in solution, he added: "Admitting, then, that water which has been stored in reservoirs or drawn through pipes of galvanized iron always contains zinc in solu-

* Hazen. Eng. News, April 4, 1907.

† Rivers Pollution Commission, 6th Report.

tion, in the form of one or more of its salts, the innocuity of those salts, in the quantities in which they occur, is attested by the experience and experiments of distinguished observers."

He further said: "At least with water fit for drinking purposes in other respects the contained zinc salts in solution do not exert any deleterious effects upon the human system. Even if all the zinc in solution were in the form of chloride, the most active poison of the zinc salts, the amount would still be insufficient to endanger health."

However willing most of us may be to agree with the doctor in his first remarks, it would be doubtful policy to follow him to the extent of this final statement.

In one instance, known to the writer, a glassful of zinc chloride solution was taken in mistake for Hunyadi water. Vomiting immediately ensued and very serious illness followed, but the final recovery was complete.

We know that certain waters can attack the metal to an objectionable degree, hence the use of galvanized iron for transmission of a water-supply should not be decided upon until examination has shown the water in question to be without material action upon the zinc coating.

Although we are aware in a general way that softness, acidity, dissolved gases and the presence of much chloride or nitrate will tend towards metallic solvency, while alkalinity and hardness are rated as protective agents, yet it is far better to actually test a water with reference to its behavior toward metals than to attempt any prophecy of its action based upon analytical knowledge of what the water may contain.

Reports recording that a water holds so many parts per million of lead, zinc or other metal are common enough, but it is rare to find advance statements of what it is capable of doing in the way of dissolving metals with which it may be brought in contact. In other words, a client who possesses a water-supply which is very desirable at its source is seldom informed of the possible damage it may sustain if conveyed through metallic piping.

After the pipes have been laid and the water admitted to them, record is made of the result as to metallic solvency, but little is found in the nature of a prophecy antedating the outlay of capital, which prophecy, had it been uttered in time, might have had material bearing upon the investment. Again, if, as occurs in a few instances, the client be told that the water under examination is capable of acting upon certain metals, he is not given the information in such quantitative form as will enable him to make comparison between it and other waters with reference to this characteristic.

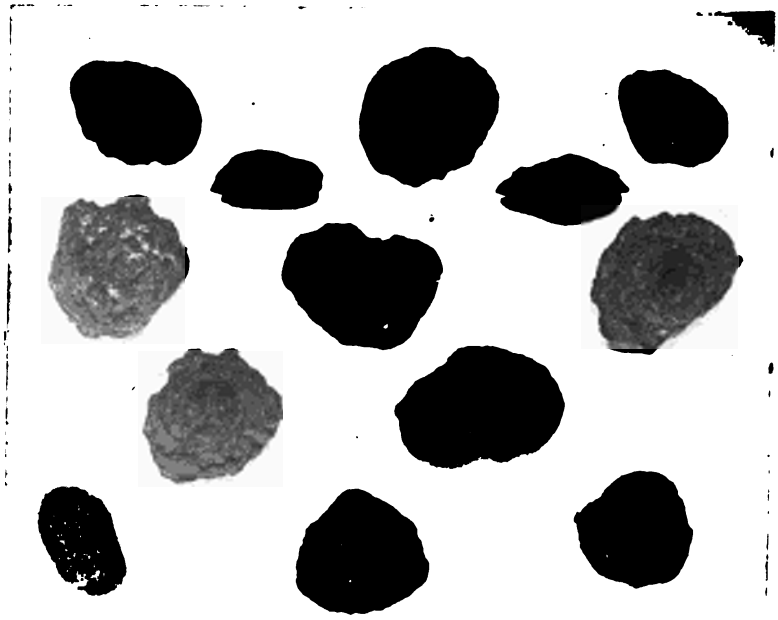
Copper. Although copper is somewhat attacked by soft water, the result is vastly less dangerous to health than is the case with lead. Very small doses of copper are apparently not harmful to human beings, while they are destructive of certain lower forms of life. It is the very reverse of lead in this particular, the latter metal being pathogenic to man and harmless to micro-organisms.*

The presence of copper in public waters does not become a question of practical importance except in the unlikely case of over " coppering " a reservoir for algæ removal.

Iron. When present, this metal is ordinarily in the water before it enters the distributing-mains, and is not a result of action upon the iron pipes. Chalybeate waters commonly hold the iron in solution as a carbonate, and less frequently as a sulphate. Inasmuch as $\frac{1}{4}$ grain of the metal per gallon (4.25 parts per million) will give a distinct taste, it would be difficult to make a supply holding that amount popular with the public, even were the water not unsuited to a variety of uses, such as dyeing and washing.

Action of water upon conduits of iron commonly results in damage to the pipe rather than to the water, either through corrosive attack tending to a weakening of the walls or else by causing a building up of interior accumulations that reduce the carrying capacity. The illustration shown on page 468 exhibits

* See J. Roy. San. Inst., xxxv. 326.



TUBERCLES FROM A 16-INCH WATER MAIN. (Full size.)

WATER PIPE ALMOST COMPLETELY CLOSED BY TUBERCLES. (Full size.)

tuberculation which has almost completely blocked a pipe $1\frac{1}{2}$ inches in diameter.

Excessive tuberculation appears to be confined to pipes of small diameter, the larger sizes seeming to accumulate layers of deposit that are comparatively thin. Nevertheless whoever has observed the operation of a "scraper" upon some miles of a large main will recall the tons of rusty tubercle material removed.

These conical masses are reddish-yellow on the surface and when newly removed are darker within, due to iron in the ferrous condition. When cut in section they exhibit concentric layers of accretions and many of them show a concavity in the center of the base. Those pictured on page 468 are from a sixteen-inch main carrying the Grafton portion of the Troy water-supply, and are shown in full size.

Cutting out tuberculations by use of a scraper will, in small-sized pipes, increase the chances of blocking the house connections. Properly applied "pipe coating" is the most efficient remedy against these concretions.

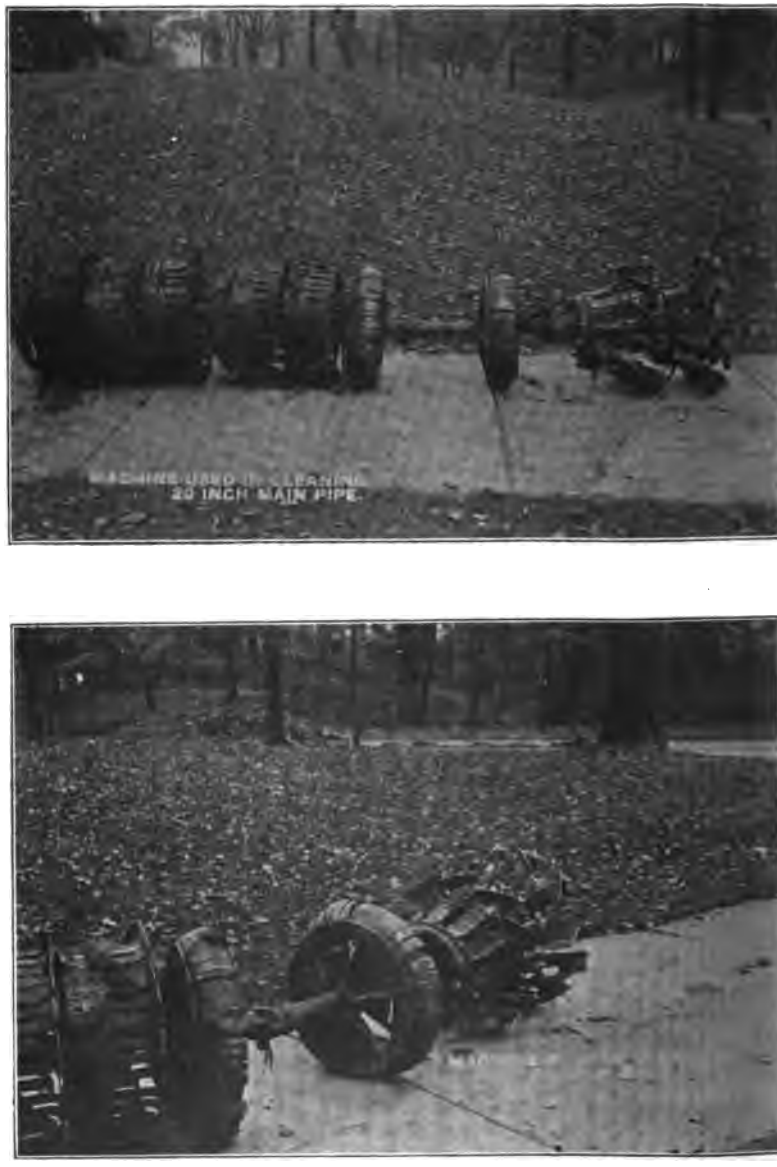
Inasmuch as the removal of tuberculations will increase the rate of subsequent pipe corrosion it becomes necessary when considering the advisability of cleaning large mains, to balance the advantage of a greater carrying capacity against the cost of frequent scraping.

Macfadzean * reports that, two years after cleaning, a sixteen-inch main had lost 44 per cent of what it had gained in carrying capacity by scraping.

Temporary deterioration of the carried water is marked in instances where the pipes lie empty a portion of the time, as when a surface pipe is drained in winter to avoid freezing. Iron corrodes very rapidly under such circumstances, and when the water is turned on again in the spring the iron oxide stains it for a considerable time.

Broadly stated, highly colored swamp waters and those high in saline contents or in dissolved oxygen and carbon dioxide belong to the class which attacks iron.

* Surveyor, 47: 772.



THE MACHINE USED IN CLEANING 20-INCH PIPE.

N. E. W. W. Assoc., vol. xxvii. Paper by Saville on Cleaning Water Mains.

Cast-iron pipes corrode more quickly in water containing an admixture of salt; as in the street-mains laid near the New York docks. "The life of a pipe is very short in such locality, and sixteen to twenty-five years is probably the limit of service." *

The following from Trautwine deals with the special action of sea-water upon iron:

"Genl. Pasley examined cannon and other metal from the wreck of the Edgar, which had been sunk in sea-water for one hundred and thirty-three years, and reports that the cast iron had generally become quite soft, and in some cases resembled plumbago. Some of the shot, when exposed to the air, became hot, and burst into many pieces. The wrought iron was not so much injured, except when in contact with copper or brass gun-metal. Neither of these last was much affected, except when in contact with iron."

Some time since the writer received from Mr. W. C. Hawley, then Superintendent of the Atlantic City Water Department, a piece of corroded cast iron which had been "blown out" from the side of a 12-inch force-main. No analysis was made of it, but in appearance it resembled compact clay, yielded to the knife like hard clay, was easily powdered in a porcelain mortar, and had a specific gravity of 2.28.

The following is from Mr. Hawley's letter: "The pipe has been laid about nineteen years under a salt meadow of deep black mud. Two separate layers of sound sod lie below the present surface grass.

"The action of this mud on steel or wrought iron is extremely severe. Wrought iron after fifteen or eighteen months looked as though it had been placed in strong acid, the fiber being brought out distinctly. The deterioration of the force-main ranged from one-half to the full thickness of the metal."

The rusting of iron is a complex process and scientists are very far from being agreed upon just what takes place during the procedure. Whitney's electrolytic theory has as many

* Jour. Am. Water-works Assoc., xii. 27.

supporters as any other, but until the specialists have reached some final conclusion the water engineer may be allowed to retain the chemical conception which has been the longest in vogue.

$$2Fe+4CO_2+2H_2O+O_2=2Fe(HCO_3)_2$$

$$4Fe(HCO_3)_2+O_2=2Fe_2O_3+4H_2O+8CO_2.$$

The above equation are to considered as suggestive only. Without doubt the actual reactions are much more complicated. It will be noted that the carbon dioxide required to start the process is subsequently released and may repeat its action indefinitely.

In the matter of resisting corrosion cast iron is apparently superior to steel or wrought iron provided the " foundry skin " be not removed.

Thwaites * showed this experimentally at some length, thereby substantiating the generally accepted view. Of course ordinary commercial brands of the metals are here referred to, for it is well known that pure iron is highly resistant to corrosion.

" Many ancient monuments and relics in wrought iron still in a good state of preservation indicate that the wrought iron of those days was decidedly superior to the modern commercial material.

" The iron pillar at Delhi is one of the most interesting relics of ancient India, and is said to date back from the year 912 B.C. This pillar, 50 feet in height, and about 16 inches in diameter, is built up of blooms, weighing about 50 pounds each, welded together. The pillar is remarkably free from rust, though the climate of Delhi is not particularly favorable for the preservation of iron exposed to the atmosphere. The surface of the iron has a bronze-like appearance, and one of the suggestions which has been put forward to account for its remarkable state of preservation is that the iron was forged on a siliceous stone anvil, and that some of the silica of the stone entered into combination with the iron, as it is known that

* Water and Water Engineering, June 15, 1915.

silica has a marked influence in resisting corrosion when alloyed with iron."

As to what should be considered the normal life of good quality cast-iron water pipe, knowledge of the locality where the pipe is to be laid must be had before an estimate can be risked. As already noted, sea-water and salt marshes are conducive to short periods of service, while in good soil the life of such pipe is so long as to exceed our present period of experience.

Boilers may be affected by water in several ways, namely, through the corrosive action of what the water may hold in solution, or, indirectly, through the secondary evils resulting from foaming and scale formation.

Tendency toward *foaming* is caused by the presence of suspended matter of organic character, or even inorganic materials if they be finely divided, also by salts of the alkalies in solution and by any substances which increase the viscosity of the water. Henderson says: *

"If a water contains over 50 grains of foaming matter (soluble salts) to the gallon (850 parts per million), it is sure to give trouble in a locomotive."

"One hundred grains per gallon is made the limit of concentration in the locomotive.† This means that the amount in the original water must be much lower. Forty to fifty grains per gallon is the limit for waters to be used in locomotives. Much higher concentration can be obtained in the stationary boiler without experiencing any difficulty."

Reduction of the concentration, at the same time removal of sludge, by blowing out the boiler, would seem to be the logical treatment for foaming, although it entails expense through loss of heat.

Any free acid is objectionable in a boiler-water, even carbonic acid, if the quantity be large. In fact, altogether too

* Engineering News, 50: 280.

† Report of Committee, Am. Ry. Eng. & Maintenance of Way Association Bulletin 83, p. 45.

little attention is paid to the deleterious action upon the metal by the gases which the water may hold in solution.

Carbon dioxide and atmospheric oxygen act upon iron at high temperature with decided energy, and such action may occur at a considerable distance from the boiler itself. The writer has observed serious effects, due to dissolved gases, upon the steam pipes many feet from the boiler.

It should be remembered that inasmuch as oxygen is more soluble in water than is nitrogen the " dissolved air " is much richer in oxygen than the atmospheric ratio calls for.

Sulphuric acid, so commonly present in mine-water, is highly objectionable. It is formed from the decomposition of iron pyrites:

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4.$$

Sundry streams of western Pennsylvania are so polluted by mine drainage as to become distinctly acid, especially during periods of low rainfall. Thus the average acidity of the Youghiogheny river for the year ending Sept. 1, 1907, amounted to 22 parts per million, measured as sulphuric acid.* The effect of such a water upon plumbing fixtures is very severe.

The liberation of free fatty acid by the steam acting under pressure upon lubricating oils of animal or vegetable origin is a common cause of corrosion. The widely known " Tilghman process " illustrates such action, for instance margarine breaks into glycerine and margaric acid when so heated.

$$C_3H_5(C_{17}H_{33}O_2)_3 + 3H_2O = C_3H_5(OH)_3 + 3H(C_{17}H_{33}O_2).$$

For this reason it is preferable to employ a cylinder-oil of hydrocarbon character.

Water containing magnesium chloride is especially to be avoided for boiler uses, because the salt decomposes at the high temperature attained, with production of free hydrochloric acid according to the equation

$$MgCl_2 + 2H_2O = Mg(OH)_2 + 2HCl.$$

* Water Supply Paper 236, U. S. Geol. Sur.

This acid being readily carried over in the steam, the damage that it works is not confined to the boiler alone.

It being known that ammonium chloride will prevent the decomposition of magnesium chloride, during evaporation, by forming therewith a stable double chloride, A. H. Allen suggests that the sodium chloride of sea-water acts in a similar way for the protection of marine boilers from the magnesium chloride found in sea-water. His remedy for stationary boilers compelled to use magnesium waters is to add common salt to the feed-water.*

In view of the bad effects of magnesium chloride upon boilers, he further contends that it should appear in the analysis to the fullest extent compatible with the total amounts of chlorine and magnesium.

Water strongly alkaline with sodium salts, as is found in certain sections of the West, is also corrosive; for instance, such a water as that from Bitter Creek, Wyoming, which contains:

	Per Million.
Calcium carbonate	13.1
Silica (clay)	3.9
Calcium sulphate	trace
Sodium sulphate	431.0
Sodium carbonate	843.1
Sodium chloride	96.3
Silica (in solution)	8.6

Such a water could be purified for boiler purposes by the use of barium chloride; but another, and possibly cheaper, method under the circumstances is that employed by Mr. A. Pennell. He writes to the author: "Calcium sulphate is added, which forms sodium sulphate and precipitates calcium carbonate. A further dose of gypsum is then added, and the water is heated to 200° F., whereupon glauberite ($Na_2SO_4.CaSO_4$) precipitates as semi-transparent crystals. All does not precipitate at this temperature, but the rest falls at boiler temperature and is blown off at intervals."

* J. Soc. Chem. Ind., vii. 800.

Boiler-scale may be classified as of two general kinds: first, that which is friable and mud-forming, such as is caused by the employment of temporarily hard water; and, second, a hard, compact, and adherent form, arising from the use of water of permanent hardness.

The hard adherent form is much the more objectionable, as a mud deposit is readily removed. The cause of the deposit of the calcium sulphate, which forms the compact scale, is found

BOILER TUBE NEARLY BLOCKED BY HARD SCALE. Full size.

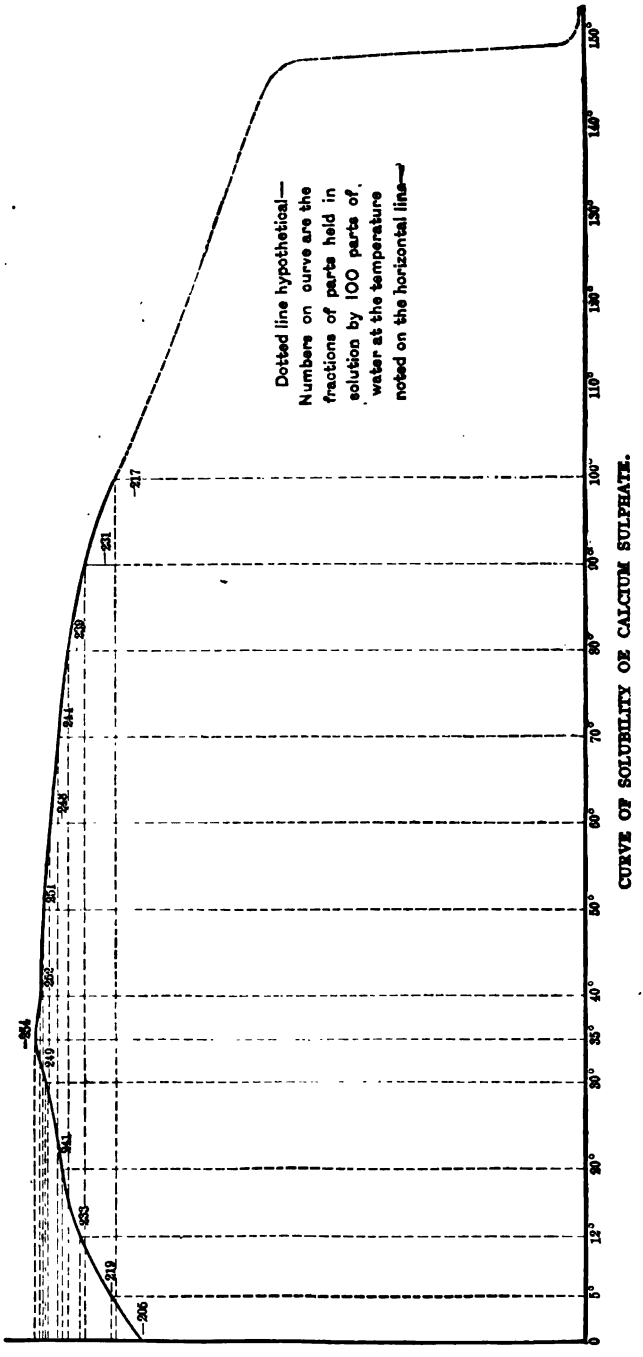
in the insolubility of that salt at the high temperature attained in the boiler. The curve of solubility shown on page 477 is seen to closely approach the zero line at a temperature of 150° C.

The writer possesses some hard, dense sulphate scale, of two inches in thickness, which was taken from the boilers of the steamer Tybee.

The heat arrested by a thick deposit of scale is ruinously wasteful of fuel.

Thus Rankine estimates * that the conductivity for heat of

* "Water Purification," Rideal, p. 201.



CURVE OF SOLUBILITY OF CALCIUM SULPHATE.

calcium carbonate is eighteen times, and of calcium sulphate is fifteen times, less than iron.

He holds that

$\frac{1}{8}$	inch scale	requires	16	per cent	additional	fuel
$\frac{1}{4}$	" "	"	50	"	"	"
$\frac{1}{2}$	" "	"	150	"	"	"

As a result of tests upon a locomotive boiler it was found that scaling to the depth of $\frac{1}{8}$ inch caused a loss of steaming efficiency equal to 10.5 per cent.*

Outside of waste of fuel, the damage to the boiler-metal resulting from the high temperature to which it must be heated in order to overcome the scale resistance must also be taken into consideration.

The deposits of the carbonates held in solution in temporarily hard water is caused by the escape of the solvent carbon dioxide upon the rise in temperature of the boiler water.

Should means other than the elevation of temperature be employed for the removal of the carbon dioxide in solution, the precipitation of the dissolved carbonates would take place with equal certainty.

Thus many years ago Dr. Clark patented a process, which still bears his name, for removing the carbon dioxide by the use of lime-water, according to the equation

$$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O.$$

The calcium carbonate formed by the equation precipitates and along with it also fall the calcium and magnesium carbonates originally held in solution in the water.

Bartow and Scholl have shown that magnesium is without value in the softening of water and that it increases the amount of sludge to be handled without corresponding benefit. Consequently a magnesium-free lime should be procured for the softening process.†

In America the " Clark process " for softening temporarily

* J. Am. Chem. Soc, xxviii. 640.

† J. Indust. and Engr. Chem. 6: 189.

hard waters is not very frequently resorted to, because our waters are commonly fairly soft, or else are permanently hard, a form of hardness for which the process is not suited.

In England, however, where chalk deposits are so plenty, this method of purification is more often seen, and even on so large a scale as that required for a city supply. At Southampton the water for 63,500 persons comes from a large well in the chalk, sunk in 1888; and it is softened by a "Clark process" plant of a capacity of 2,000,000 gallons daily. The water receives a charge of 10 per cent of its volume of lime-water in a mixer and is then discharged into a softening cistern 38 by 23 by 3 feet. After partial precipitation, the milky water passes to perforated filter-plates covered with cloth. The cost of this plant was about $50,000. It produces 1½ tons of precipitate daily, and uses up ½ ton of lime for the purpose.*

For boiler purposes the expensive filter-presses would not be warranted, and simple settling-tanks should be substituted.

Care should be taken to avoid the introduction of more lime-water than the reaction calls for, as a large excess would of itself cause a boiler incrustation. The brown precipitate produced by pouring a solution of silver nitrate into lime-water is a convenient indicator for use with the Clark process. As soon as the said brown precipitate appears, in a sample of the treated water, upon addition of a few drops of silver nitrate solution, the further introduction of lime-water should cease.

The softening of permanently hard water may be accomplished by the addition of a solution of sodium carbonate, which causes a precipitation of insoluble calcium carbonate:

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$

Whatever method is used the softening process should be applied outside the boiler, as by doing so the deposited sludge does not have to be subsequently blown off. Moreover if preliminary heating of the feed-water be undertaken it can be so conducted as to remove from solution any corroding gases.

As a matter of practice, however, the boiler itself is in many

* Engineering, March 11, 1892; see also Engineering News, April 16, 1892.

instances forced to serve as a reaction chamber and the dose of chemicals is added directly.

Complete softening is not contemplated, because of additional expense and for the reason that a slight film of scale in a boiler is rather beneficial than otherwise.

As showing the views held by those who make use of boiler waters on a large scale, the following extracts from letters, written to the author during 1915, may be of interest. They are from Engineers of Tests connected with some of the largest and most important railroads in the United States:

No. 1. "About the best water we have analyses from 120 to 170 parts per million of hardness. We would, of course, prefer water with not over 85 parts per million of hardness and consider a water containing 255 to 340 as poor, and above that as bad.

"The limit of hardness in water which can be successfully treated depends largely upon local conditions and the chemicals with which the water is treated. Lime and soda-ash are the ordinary chemicals used on this railroad, although more expensive chemicals, such as barium compounds, are used in some places. I do not believe railroads would resort to the use of the expensive chemicals in question unless the water already carried 340 to 510 parts per million of sodium sulphate.

"The degree of hardness which can be successfully treated will vary with the importance of the water station. At some outlying points where comparatively little water is used it can be treated without any undue trouble from foaming in engines when the hardness is as high as 1275 parts per million.

"It would not be advisable, however, to attempt treatment of water of this character at an important station where all engines take a large amount of water."

No. 2. "I consider a water as good for boiler purposes if it has a hardness of not over 170 parts per million, provided not more than 50 to 70 parts per million of this hardness is due to calcium and magnesium sulphates.

"I would consider a water having a total hardness of 680 parts per million and over, of which 255 parts per million is classified as permanent hardness, as too bad for boiler purposes. I have found from practical experience that a water containing over 500 parts per million of permanent hardness cannot satisfactorily be treated by the soda-lime process, as a water so treated as to remove all the incrusting sulphates would cause difficulty from foaming in locomotive boilers."

No. 3. "A good water would be one with a hardness of less than 170 parts per million; a poor water would have a hardness of from 340 to 510 parts per million. A water above 680 parts per million would be considered too bad for use and we would not care to go to the expense of treating water of this character, as above that figure it is not profitable."

No. 4. "In our experience a good water contains less than 85 parts per million of total residue, is free from acid salts, magnesium chloride, and other constituents which might be corrosive and it should contain a small amount of carbonates.

"The point at which it becomes profitable to soften water depends very largely on the type of boiler in which it is used." In some of our boilers "we are actually treating water that contains only 100 to 120 parts per million of total residue and the treatment is undoubtedly profitable. In most cases we have succeeded in successfully treating boiler water containing up to 510 parts per million total residue. Some of our subsidiary lines are treating water containing from 510 to approximately 1020 parts per million of total residue with some degree of success. Water containing a higher residue than this is not used except in case of absolute necessity."

No. 5. "In regard to the rating of boiler waters on this system, we have a scheme which is shown as follows."

INCRUSTING RATING (PARTS PER MILLION)

1. Very good. Water having sodium carbonate and hardness less than 350.

2. Good. Water having sodium carbonate and hardness

greater than 350. Water having sulphate hardness less than 50 and total hardness less than 200.

3. Fair. Water with sulphate hardness between 50 and 100 and total hardness less than 300, or total hardness between 200 and 300.

4. Bad. Water with sulphate hardness between 100 and 150 and total hardness less than 500, or total hardness between 300 and 500.

5. Very bad. Water with sulphate hardness greater than 150 or total hardness greater than 500.

FOAMING RATING (PARTS PER MILLION)

A. Very good. Alkali salts less than 70.
B. Good. Alkali salts between 70 and 150.
C. Fair. Alkali salts between 150 and 250.
D. Bad. Alkali salts between 250 and 400.
E. Very bad. Alkali salts over 400.

No. 6. Classification for boiler use (parts per million).
Good. Water with 0 to 100 scale-forming solids.
Fair. Water with 100 to 170 scale-forming solids.
Poor. Water with 170 to 240 scale-forming solids.

Waters for boiler use (in Connecticut) have been classified by G. H. Seyms as follows, based upon the total solids stated in parts per million: *

Good, less than 250.
Fair, between 250 and 500.
Unfit, over 500.

Scale from sea-water consists mainly of calcium sulphate and magnesium hydroxide; in fact, as Driffield has shown, magnesium occurs in these deposits as hydroxide, although precipitated as carbonate, the conversion to the former being accomplished by the high temperature of the boiler.†

* Water Supply Paper 232, p. 169.
† J. Soc. Chem. Ind., vi. 178.

Such a change is more likely where the scale is in touch with highly heated metal, and it may be represented by the equation

$$MgCO_3 + 2H_2O = Mg(OH)_2 + CO_2 + H_2O.$$

A very large number of boiler-scale "preventives" and "eradicators" have been placed upon the market which are peculiar for nothing, as Professor C. F. Chandler has well said, except their high price. Such as have any value whatever may be duplicated, at very little expense, out of quite common materials.

Unfortunately, many of these preparations are perfectly inert, and not a few are positively harmful. In the latter class, for instance, the writer has found such material as acid sodium sulphate colored with logwood. Such a preparation acts upon metals with half the intensity of pure sulphuric acid, and its continued use must surely work injury to the boiler. A large class of these "preventives" aim not at the actual prevention of a deposit, but rather seek to alter its physical character.

Thus many of them are of a mucilaginous order, and they so envelope the precipitating particles of mineral matter as to prevent their mutual coherence. A further action of such of the compounds as contain insoluble material like sawdust is to provide separated nuclei, about which crystallization of the scale-forming salts may occur. In the first instance, such an increase in the viscosity of the water may follow as to cause serious frothing or "priming," and in the second there is additional danger of getting solid substances carried over into the moving parts. It is very questionable if as desirable results can be obtained at reasonable price by the employment of any of the "eradicators" as may be had by the use of ordinary sodium carbonate added in proper quantity.

Good results are obtainable from the use of an iron-zinc couple, secured by attaching plates of zinc to the boiler bracings. Protection of the iron follows at the expense of the zinc plates.

The *excess lime* method of softening and disinfecting water, proposed in 1912 by Dr. A. C. Houston of the Metropolitan Water Board (London), is a modification of the Clark process, and is fully described in the Eighth Research Report. Briefly stated, the process consists in dosing a fraction of the volume of water to be treated, say 75 per cent, with the full quantity of lime intended for all of the water and then, after an interval of twenty-four hours, adding the remaining 25 per cent of the water. The heavy overdose of lime used in the first fraction will, during the twenty-four hours interval, kill objectionable organisms that may be present and will also furnish the proper softening dose for both portions when they are brought together. The smaller part is separately sterilized by storage or other means before the mixture is made. The method has not been tried in America. The claim made in its favor is the lowering of cost due to the very cheap means taken to sterilize three-quarters of the quantity of water handled. The process is preliminary to filtration.

Houston says: "When 1 part of quicklime (about 75 per cent CaO) is added to 5000 parts of raw Thames water about 0.007 per cent free CaO is left in the mixture and this excess is sufficient to kill *B. coli* in from five to twenty-four hours. To neutralize the excess CaO, not less than 25 per cent of stored water must subsequently be added."

Industrial waters should be in most cases "soft" in character, although a hardness due to calcium sulphate is preferable for the use of *breweries* that make light-colored beer.

The *laundry interests* in particular require a soft water not only to lessen the expense due to soap destruction (which amounts to ten cents per million gallons of water for each additional part per million of hardness, as shown by Whipple), but also because the "lime soaps" formed by the use of hard water are likely to enter the body of the cloth in the shape of small lumps which are difficult to remove. The laundries are also desirous of avoiding water containing iron as its use causes rust spots upon white goods.

For *paper making* clearness of the water employed is a prime requisite. Iron, even in solution, is objectionable for practically the same reason as in the laundry business; it spots the finished product. As differing from the laundry-man, however, the paper-maker prefers a somewhat permanently hard water to a very soft one for the reason that it is less wasteful of the calcium sulphate "loading" that is frequently employed.

In *dyeing* processes the absence of turbidity and iron is the chief demand, although softness is also important. This is also true for the *tanning* industry.

Permutit, an artificial zeolite, has of recent date been introduced as a softener of water. In general appearance it resembles ordinary filter-sand, but the grains possess considerable porosity. It is made by fusing together, in suitable proportions, quartz, clay and soda-ash, the result being represented by the formula $Na(Al_2Si_2O_8)$. When water carrying either $CaSO_4$ or $CaCO_3$ filters through a bed of this material the calcium and sodium exchange places, the water becoming softened as per the equations:

$$2Na(Al_2Si_2O_8) + CaSO_4 = Ca(Al_2Si_2O_8)_2 + Na_2SO_4$$

$$2Na(Al_2Si_2O_8) + CaCO_3 = Ca(Al_2Si_2O_8)_2 + Na_2CO_3.$$

The calcium permutit so formed will slowly react with a 10 per cent solution of common salt in the following manner:

$$Ca(Al_2Si_2O_8)_2 + 2NaCl = 2Na(Al_2Si_2O_8) + CaCl_2.$$

Hence, if, after using the apparatus all day for water softening the permutit bed be allowed to rest during the night covered with salt solution, regeneration of the filter becomes completed by morning and, after draining off the solution of calcium chloride to the sewer, the plant is again ready for its work of water softening during the day. Thus the upkeep of the process is reduced to supplying the daily amount of common salt used. For laundry purposes the result is favorable. In one small public laundry in Troy, where a Permutit plant was

installed at a cost of $1200, the manager finds a saving of $15 weekly in soap, at an outlay of $2 weekly for the salt required. The soap hardness of the raw water used averages about 40 parts per million.

The use of manganese permutit possesses some advantages as a method for manganese removal.

Representing sodium and manganese permutits by the shortened formulæ Na_2P and MnP, the reactions for making manganese permutit and its use for removal of manganese from the water would stand:

$$Na_2P + MnCl_2 = MnP + 2NaCl$$

$$MnP + 2NaMnO_4 = Na_2P + MnO \cdot Mn_2O_7.$$

$$Na_2P + MnO \cdot Mn_2O_7 + 2Mn(HCO_3)_2 = Na_2P + 5MnO_2 + 4CO_2 + 2H_2O.$$

The MnO_2 formed is removed daily by a back-wash which requires 1 per cent of the treated water.*

For boiler use the Permutit process solves the question of scale formation, but introduces the possibility of "foaming" if the hardness of the raw water be high, on account of the quantity of sodium salts added to the water. In this particular it does not differ from the older method of softening sulphate waters by use of soda-ash. In either case a water may be too hard to permit of economic softening.

Grease balls sometimes occur in boilers and are formed by oil or grease in the water uniting with precipitated calcium and magnesium salts also present. (See page 487.)

The resulting insoluble "soaps" become rolled together by motion of the water until balls of considerable size are formed. The one here shown is from the *Traveler's Standard*, III: 205, and it is stated to have measured three inches in diameter.

Red water, a caption now often seen, describes the unsightly turbidity of iron oxide that follows heavy corrosion

* See J. Indust. and Engr. Chem., 8: 160.

of uncoated hot-water service-pipes, and those of a cheap brand of galvanized iron. Nor is the corrosion confined to hot-water lines, although more commonly occurring in them than in pipes carrying cold water. When water is low in alkalinity and high in both dissolved oxygen and carbon dioxide, "red water" is likely to occur, if poorly coated iron pipes be installed in the hot-water system. Its occurrence seems to

"GREASE BALL."

vary with the seasons, being more frequently noticed during the colder months, when dissolved gases are carried by the water in greater quantity.

Mechanical filtration has been blamed for the appearance of red water, the claim having been made that the alum used in the process causes corrosion by virtue of its acidity. Of course an overdose of alum, sufficiently great to produce acidity, would certainly attack iron, but in a modern, well-managed filter-plant no such overdosing is permitted to occur.

It may well be that the clear water furnished by the filter has had removed from it certain organic constituents that before filtration acted as protective agents to the iron surfaces and

thus allowed the corroding effect of a soft water to become more evident.

When filtering a water likely to cause corrosion, if the alkalinity should be found to be near the amount required to react with the dose of alum used, it should be raised by the addition of lime or soda-ash to a point nearly or quite double that value (7.5 parts per million alkalinity per grain of alum used in each gallon of water), say to 15 parts per million so that undue softness, with consequent " red-water " troubles may be avoided.

Thorough protection of the iron piping should be secured by a well applied zinc coating or, better still, the hot-water line may be constructed of brass, or, if the pressure permit, of lead.

If arrangements can be made whereby the water can be heated in an open heater before admission to the boiler, the consequent removal of dissolved gas will prevent corrosion in either the boiler or the service pipes.

R. S. Weston finds that removal of carbon dioxide by aeration, although only partial, will do much towards preventing the corrosion of iron.

Removal of the gas by means of lime or soda-ash would also lead to the same result.*

The actual bulk of the material formed by pipe corrosion is often very large. Whipple, who has measured it, says:†

" It hardly seemed credible that so much iron rust could be derived from the pipe itself, but experiments showed that each volume of metallic iron was capable of producing upwards of 10 volumes of iron rust in a moist condition, and calculations showed that in order to completely fill a 1½-inch pipe it would be only necessary to have the metal of the steel reduced on an average by less than $\frac{1}{27}$ inch, or in a 1-inch pipe by $\frac{1}{10}$ inch."

* See Report by Jackson and Hale, New York Department of Water, 1912.

† Report to Board of Water Commissioners, Springfield, Mass., 1910.

APPENDIX A

ANALYSES OF SEA WATERS (FROM STILLMAN)

(Parts per Million.)

	Total Solids.	Ca	Mg	Na	K	NH_4
Atlantic Ocean, 41° 18′ N.; 36° 28′ W.	38,400	556.8	1,198.1	17719.7	668.2	
Pacific Ocean, 28° 11′ S.; 93° 24′ W.; 420′ deep	35,220	475.2	1,471.4	10,232.6	633.6	
North Sea bet. Belgium and England	32,800	324.4	1,158.2	10,205.7	353.6	
Baltic Sea	17,710	36.3	611.5	5,894.1		
Mediterranean Sea, off Cette	37,706	14.1	1,310.4	11,706.2	264.3	
Black Sea off Crimea	1,766	130.5	662.2	5,512	97.5	
Caspian Sea	6,296	191.6	409.8	1,444	139.7	
Dead Sea	240,483	9000	19,883	47,918	6,385.1	18

	Al	Fe	Mn	CO_3	SO_4	Cl	Br
Atlantic Ocean 41° 18′ N.; 36° 28′ W.					3029.8	20,839.7	387.8
Pacific Ocean 28° 11′ S.; 93° 24′ W.; 420′ deep	.....	.....	.....	.....	3826.6	19,321.3	239.4
North Sea bet. Belgium and England	.....	.....	.....	.....	2590.2	18,167.9	
Baltic Sea	.....	.....	.....	.....	718.9	10,386.4	
Mediterranean Sea off Cette	.....	2.8	.....	67.9	2942.8	20,526.9	433.5
Black Sea off Crimea	.....	127.1	.....	247.5	1250.2	9,574.5	5
Caspian Sea	40.	.....	.....	77.3	1337.2	2,737.7	
Dead Sea	153.4	11.7	25.8	.....	470.9	154,442	2176.7

APPENDIX B

RIGHTS AND DUTIES REGARDING THE POLLUTION OF STREAMS

Taken from a paper by Edwin B. Goodell, on "Water Supply and Irrigation," published by the United States Geological Survey:—

1. Rights and Duties of Riparian Owners

Every riparian owner has the right—

1. To use the waters of streams, navigable or otherwise, which flow across or along his property for the ordinary purposes incidental to domestic life and agriculture, including grazing.

2. To use such waters for water power, and for all kinds of manufacturing purposes which do not sensibly diminish the quantity which flows on for the use of lower proprietors, nor change the quality of the waters to any appreciable extent, nor interfere with the use of the stream, if navigable, by the public.

3. To have such waters flow to him from the premises of higher proprietors not unreasonably diminished nor diverted, nor rendered impure by the farming or domestic uses to which the waters are subjected by higher proprietors.

4. To have such waters flow to him not sensibly changed in quality by any manufacturing or other uses to which they may have been put by higher proprietors.

5. To have such waters flow to him in their natural bed, unpolluted by any deposits of filth, or any other substance in the bed or channel previously traversed by them. But 3, 4, and 5 do not apply to riparian owners in those States in which the doctrine of prior appropriation is the law.

Conversely, it is the duty of every riparian owner—

1. To so guard his use of the waters of streams which flow

across or along his property for domestic and agricultural purposes as not unreasonably to divert, nor diminish, nor render impure such waters.

2. To refrain from every use in manufacturing which will divert or sensible diminish the quantity of the waters which flow onward to the lower proprietors or render them appreciably different in quality.

3. To refrain from depositing any filth or other substance in the bed of such streams in such a manner or to such an extent as will cause the waters to flow to the lower proprietors out of their natural bed or will in any wise pollute them or render them impure.

Where the doctrine of prior appropriation is in force the appropriator must confine his use of the appropriated water to the use for which he had appropriated it and take only so much as is reasonably necessary to accomplish that purpose. He may not pollute the stream wantonly, nor by using it for purposes not included in his appropriation. Subject to these restrictions, the prior appropriator has the right to divert from the stream and use as much of the water as is necessary to accomplish the purpose for which it was appropriated.

II. Rights and Duties of Municipal Corporations

Considered as corporate entities, municipal corporations have such rights and powers only as are conferred upon them by statute, either expressly or by necessary implication.

When, under due authority, they become the owners of lakes, reservoirs, and natural streams, they have the same rights to pure water, and are charged with the same duties as are other riparian proprietors.

If authorized to construct a system of sewage draining into a stream, such authority does not exempt them (excepting the State of Indiana) from the duty not to pollute the stream to the damage of lower proprietors.

The rights of property owners, specified in 3, 4, and 5 above, are property rights and cannot be taken away from owners for public use except upon payment therefor of an amount deter-

mined by constitutional condemnation proceedings authorized by statute.

Therefore, until municipal corporations have, by such proceedings, acquired the right of all lower proprietors and paid for them, they are required in all cases to refrain from the pollution of streams to the same extent as private owners.

III. Rights and Duties of the Public

By "the public" is meant that indefinite number of individuals, whether larger or smaller, who occupy as a common habitation a neighborhood, village, town, state, or country. Rights and duties which affect inhabitants of the neighborhood, village, town, state, or country as a whole, or a considerable but indefinite number of them, are called "public" rights and duties.

The public, in this sense, aside from the right to use navigable waters for commerce, has the right to enjoy the natural waters and the air which passes over them, so far as life and health are affected by these elements, in a condition so near that in which nature left them that their use will not destroy nor threaten life nor injure health.

And, reciprocally, the public, and each member of it, is charged with the duty not to pollute the natural waters upon which the community depends for life and health in any manner that will render the continued use of the waters, or of the air which passes over them, destructive of or injurious to the life or health of the community.

Public Rights and Duties Enforced by Statute

The rights and duties attempted to be expressed under III. have received some recognition by the Courts apart from statutory enactments. They have been enforced chiefly, however, through legislation. These rights and duties have received full recognition, and an active effort has been made to provide an efficient sanction for their enforcement by the Legislature of all the Statutes included in Class II. and Class III., as hereinbefore stated. These classes include thirty-eight of the States and territories.

These statutes, not being in derogation of common-law rights, have been construed as remedial statutes and not unconstitutional, although in some cases they may seem to interfere with prescriptive rights. No one can acquire by prescription a right to do an act which menaces public health or destroys public comfort.

It will have been noticed that public opinion, as expressed in public laws, is steadily progressing in the direction of a full, complete and comprehensive enforcement of all the rights and duties of riparian owners, of municipal corporations, and of the public, as summarized above. Each advance in statutory regulation is an advance in that direction, and more especially in the direction of regulating and enforcing public rights and municipal rights and duties.

Private owners, from time immemorial, have been active in protecting their riparian rights as against other private owners. But the effect of pollution upon public health has not, until a comparatively recent period, been brought prominently into notice. The pollution of streams by cities and private persons has, accordingly, not received the attention which it deserved. This state of affairs is now rapidly passing away. Courts have shown themselves fully alive to the existence and validity of public rights in that respect, and the Legislatures in Class III., comprising the States of Connecticut, Massachusetts, New Hampshire, New York, New Jersey, Minnesota, Vermont and Pennsylvania, which have come into this class by legislation enacted in 1905, have made enactments calculated so to control such pollution as eventually to prevent all danger to public health.

APPENDIX C

TYPHOID FEVER CONTRACTED FROM DRINKING A POLLUTED WATER IS DECIDED TO BE "AN ACCIDENT"

IN 229 Federal Reporter 552 the decision of the United States Circuit Court of Appeals reads as follows:

The defendant in error, the Pacific Gas and Coke Co., being engaged in the construction of a gas plant and having employed in the work a large number of men, secured from the Aetna Life Insurance Co., the plaintiff in error, a policy entitled by the latter "contractor's employers' liability policy," by which in consideration of certain premiums which the case shows the defendant in error paid, it agreed to indemnify the assured (within certain amounts within which the present case falls) against loss and expense arising or resulting from claims upon the assured for damages on account of bodily injuries or death accidentally suffered, or alleged to have been suffered, by an employee or employees of the assured by reason of the business as described and conducted at the locations named in the policy, with certain exceptions not applicable here. In the course of the work certain of the employees of the Gas and Coke Co. contracted typhoid fever from the water furnished them by the latter, on account of which that company was compelled to pay damages to such injured employees to recover the aggregate amount of which from the insurance company the present action was brought. And the sole point here presented is whether the harm so done to the workmen constituted a bodily injury accidentally received or suffered by them, within the meaning of the policy in question.

Of course it is not and cannot be doubted that the workmen were bodily injured by the drinking of the water in the course of the work, for it contained typhoid germs, which gave them typhoid fever; but it is insisted on the part of the plaintiff in

error that in drinking the water they were but satisfying a natural want, and that in doing so there was no accident about it. It is readily conceded, of course, that there could be no accident in merely drinking water; but it is just as certain that the men would not have drunk it had they known that the water contained typhoid germs. The accident consists in that unexpected happening. Among the definitions of the word "accidental," in most, if not in all, of the dictionaries, is the happening of "something unexpectedly, unintentionally." Suppose, instead of containing typhoid germs, as in the present case, the water that the employees of the assured consumed had contained some of the most virulent poisons, would anyone contend that the injuries resulting therefrom could not be properly held to have been accidentally inflicted? We think not, and yet, in our opinion, there is no substantial distinction between the case supposed and the case at bar.

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